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LEAD–SILVER MINERALIZATION IN THE CLARK FORK DISTRICT, BONNER COUNTY, IDAHO.[1]

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ABSTRACT.

The lead-silver deposits in the Clark Fork district in Bonner County, Idaho, resemble those in the nearby Coeur d'Alene region, but some of the deposits have been substantially enriched by the late addition of hypogene silver and antimony minerals. The unenriched ore consists dominantly of galena, which is accompanied by lesser amounts of siderite, quartz, and sphalerite and by still smaller quantities of pyrite, arsenopyrite, tetrahedrite, bournonite and calcite. Ore that has been enriched by the addition of late hypogene silver and antimony also contains various lead sulphantimonites and sulpharsenites, copper-lead sulphantimonite, silver-lead sulphantimonite, and ruby silver. Minerals formed during the enrichment include boulangerite ($5PbS \cdot 2Sb_2S_3$), geocronite ($5PbS \cdot Sb_2S_3$), meneghinite ($4PbS \cdot Sb_2S_3$), semseyite ($9PbS \cdot 4Sb_2S_3$), jordanite ($4PbS \cdot As_2S_3$), guitermanite ($3PbS \cdot As_2S_3$), bournonite ($Cu_2S \cdot 2PbS \cdot Sb_2S_3$), freieslebenite ($2Ag_2S \cdot 3PbS \cdot 2Sb_2S_3$) and pyrargyrite ($3Ag_2S \cdot Sb_2S_3$). Some of the minerals in this younger group are rare elsewhere, and their local abundance is one of the most interesting features of the Clark Fork mineralization.

INTRODUCTION.

THE Clark Fork district, which is about 35 miles by airline northwest of the center of the Coeur d'Alene mining region in Idaho, has an unusual mineralization. Its lead-silver deposits resemble those in the Coeur d'Alene region [2] but at least two of them have been enriched by the addition of late hypogene silver and antimony minerals, several of which are rare elsewhere.

The deposits are in the Belt series (pre-Cambrian) as fillings and replacements along minor low-angle thrust and high-angle reverse faults, which genetically are related to the Hope fault, a great transverse earth fracture which provides the same sort of structural background for this district that

[1] Published with the permission of the Director, Geological Survey, U. S. Department of the Interior.

[2] Ransome, F. L., and Calkins, F. C.: The geology and ore deposits of the Coeur d'Alene district, Idaho. U. S. Geol. Survey Prof. Paper 62, 1908.

the famous Osborn fault does for the Coeur d'Alene region.[3] The mineralization has not been so extensive as in the Coeur d'Alene region, but the deposits, though comparatively small, are rich, in part because of the compactness of the ore and in part because of the late hypogene enrichment. Since the late twenties the district has been the most important producer of lead-silver ore in northern Idaho outside of the Coeur d'Alene region, the production up to the end of 1941 having been more than $1,200,000, mainly from the most recently discovered mines, the Hope (1923) and the Whitedelf (1926).[4]

Except for the assemblage of late hypogene silver and antimony minerals, the Clark Fork ore is like the Coeur d'Alene lead-silver ore,[5] consisting dominantly of galena, which is accompanied by lesser quantities of siderite and

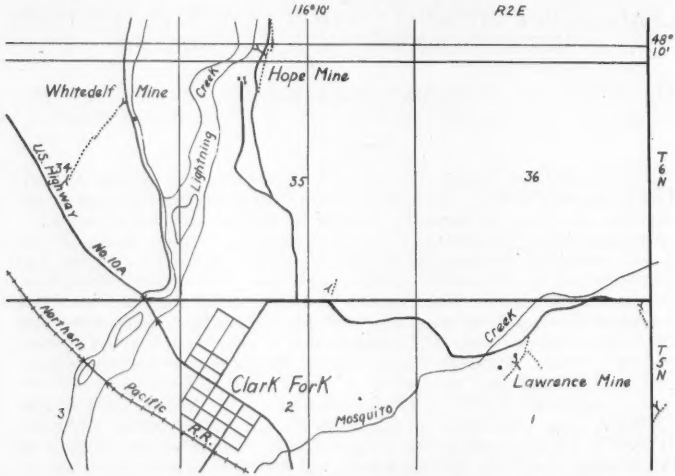

FIG. 1. Sketch map showing the location of the Whitedelf, Hope, and Lawrence mines in the Clark Fork district, Idaho.

sphalerite and still smaller amounts of several other minerals. One mine, the Lawrence (Fig. 1), contains no minerals other than these, but the two other important mines, the Whitedelf and Hope, have received additions of various complex lead sulphantimonites and sulpharsenites, copper-lead sulphantimonite, silver-lead sulphantimonite, and ruby silver. These younger sulphosalts were added after the earlier filling had been reopened by renewed faulting; deposits not reopened do not contain them. The early mineralization is distinctly of the Coeur d'Alene type; the later, which is but meagerly repre-

[3] Umpleby, J. B.: The Osborn fault. Jour. Geol., vol. 32, pp. 601–614, 1924.

[4] The Geology and the Ore Deposits of the district are to be described in detail in a report in preparation to be entitled "Geology of the lead-silver deposits of the Clark Fork district, Bonner County, Idaho." U. S. Geol. Survey Bull. 944b, 1945.

[5] Umpleby, J. B., and Jones, E. L., Jr.: Geology and ore deposits of Shoshone County, Idaho. U. S. Geol. Survey Bull. 732, pp. 41–48, 1923.

sented in the Coeur d'Alene region, gives the Clark Fork ore its own unusual character.

As many observers associate sulphosalts with supergene as well as with low temperature hypogene processes, certain pertinent data are here given which indicate that the late enrichment in the Clark Fork district, except perhaps for pyragyrite, is hypogene rather than supergene. The district is in the region that was occupied by the Cordilleran ice sheet during Pleistocene time and was deeply scoured by a tongue of ice that extended up the valley of the Clark Fork of the Columbia River. Such oxidized and supergene-enriched ore as may have existed at that time was removed by the deep glacial scouring that bared the primary ore at the surface. Since the disappearance of the ice, weathering of the ore has been negligible and mining of primary ore has been carried on from the very surface. All signs of oxidation generally disappear at depths of a few feet. As the region has a humid climate, the groundwater stands close to the surface, but the distribution of the sulphosalts apparently

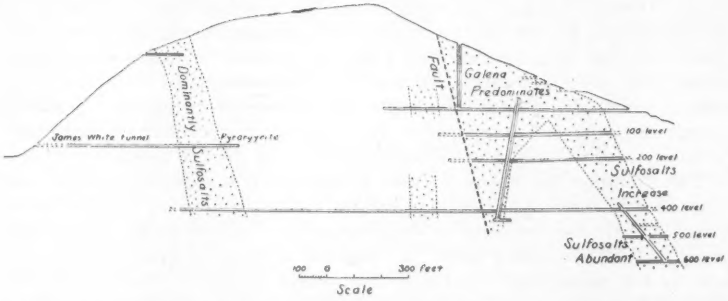

FIG. 2. Longitudinal section along the Pearl vein at the Whitedelf mine showing location of ore shoots and the distribution of galena and sulphosalts within the shoots.

has no relation to the water table, most of the silver- and antimony-rich ore, as shown in Fig. 2, having been found at depths of several hundreds of feet below the water table, increasing in amounts with increasing depth. The only pyrargyrite that has been found is in the southwest ore shoot at the Whitedelf mine (James E. White tunnel) not far beneath a steep slope where some groundwater circulation is possible.

WALL-ROCK ALTERATION.

Because the wall-rock alteration is an integral part of the mineralizing process and precedes the introduction of most of the ore, a chronological development of the picture demands that it be treated first. As in the Coeur d'Alene district the rock in and along the mineralized fault zones has lost its original blackish, reddish, or dark-greenish colors, all of it now having a pale-greenish cast. The change is generally more pronounced along the more

highly mineralized fault zones, but it may be observed in various degrees of intensity along all the fault zones that permitted circulation of mineral-bearing solutions. It is natural to infer that the bleaching was caused by the action of the mineralizing solutions, and this inference is confirmed by microscopic study.

Under the microscope the bleached rock shows abundant tiny flakes of sericite; generally irregular veinlike masses and embedded crystals of siderite; here and there small crystals of tourmaline; and, especially near the ore seams, much quartz and some disseminated crystals of pyrite and arsenopyrite. The bleaching appears to be largely associated with the formation of sericite, which is distributed to the very borders of the zones of alteration. The sericite has a pale-greenish color, which accounts for the greenish cast of the altered rock.

The sericite has replaced much of the quartz and calcite of the original rock, and in places it has replaced the rock altogether. Other minerals, in turn, partly replace the sericite. Siderite cuts the sericitized rock and encloses fragments of it, and where the mineral is abundant it has largely replaced the sericite. Quartz has not only replaced sericite, some of which is retained as remnant inclusions, but also penetrates and replaces siderite along fractures. Some of it thus is in veinlets, but a part of it forms irregular fine-grained masses that penetrate sericitized and siderite-impregnated rock, retaining remnant grains and patches of sericite and siderite as inclusions. Scattered crystals of pyrite and arsenopyrite may accompany the quartz, particularly the quartz of the silicified zones bordering some of the ore seams.

The alteration has not progressed uniformly; it is especially intense and widespread in certain places and in certain rocks. It appears to reflect more or less directly the intensity of mineralization. Sericite is the most widespread of these secondary minerals. Siderite is confined mostly to the rock close to the mineralized fractures. Secondary quartz is less widely distributed; it appears to be confined, like pyrite, to the immediate vicinity of the ore.

EARLY MINERALS (COEUR D'ALENE STAGE).

The minerals deposited during the early (Coeur d'Alene) mineralization include galena, sphalerite, pyrite, arsenopyrite, tetrahedrite, bournonite, siderite, quartz, barite, and possibly rhodochrosite; but the minerals that may be readily distinguished are limited to galena, sphalerite, and siderite, the others generally being visible only under the microscope. Deposition during this stage was apparently continuous except for slight interruptions concomitant with minor faulting movements.

Galena.—Galena, the most abundant of the early minerals, is, except in a few ore shoots, composed largely of lead sulphosalts, the principal ore mineral, being the source of most of the lead and an appreciable part of the silver. Where the ore has not received additions of the younger silver and antimony minerals, it contains 14 to 15 ounces of silver to the ton, or about 0.20 ounce of silver to each per cent of lead. Deposits without sulphosalts are composed of 90 per cent or more of galena.

Most of the galena shows the effects of rather intense deformation, asso-

ciated particularly with the movements that reopened the early filling prior to the introduction of the younger silver- and antimony-bearing solutions. The galena cubes are now mashed or granulated and show a pronounced flowage structure that becomes visible in polished sections after light etching with hydrochloric acid. Where deformation has been less pronounced, notably in the more central parts of the galena bodies, the cleavage of the galena is curved or bent.

The galena appears to be one of the youngest of the early minerals. It commonly encloses scattered irregular grains of pyrite, tetrahedrite, and sphalerite. It also cements brecciated masses and grains of sphalerite and in places it forms tiny veinlets that cut the sphalerite. Where it has been deposited in openings, it tends to form a crust on sphalerite or, if sphalerite is absent, on siderite; but where siderite is absent or has been largely replaced, the galena may penetrate and replace earlier quartz or altered country rock. The only mineral of this stage of deposition to cut or fill fractures in galena is calcite.

Sphalerite.—Sphalerite is present in small but variable quantity in all the deposits, but since it rarely constitutes more than 5 per cent and commonly no more than 2 to 3 per cent of the ore, no attempt has been made until recently to recover it. It is not uniformly distributed through the ore but is more abundant in some ore shoots than in others and is more abundant on lower than on higher levels of the mines.

Much of the sphalerite has a distinctive reddish-brown color. Some of it is extensively brecciated and has locally even been crushed to a powder which coats the surface of the ore. Part of it is in and along the galena as small lenses, pods, and bunches, which are less than an inch to several inches long and a fraction of an inch wide, but most of it forms scattered granules or small veinlets in the wall rock.

As the grains and brecciated masses of sphalerite are cemented and partly replaced by massive galena and also are penetrated by tiny galena veinlets, the sphalerite is the older of the two minerals, but, like the galena, it encloses scattered remnants of pyrite and less commonly of arsenopyrite. The sphalerite penetrates and replaces siderite, quartz, and the altered country rock, and it is therefore one of the younger minerals of the group. Sphalerite that penetrates and replaces the siderite and altered country rock generally forms irregular ramifying veinlets which may be cut off sharply and penetrated by bands and stringers of the galena; that which has been deposited in openings forms layers next to the walls, commonly as a coating on siderite or quartz crystals. Along the edges of massive ore seams it usually forms brecciated grains cemented by galena. Where the ore is dominantly galena, the sphalerite is almost entirely restricted to stringers in the bordering wall rock.

Tetrahedrite.—Tetrahedrite is present in variable but small quantity in all the ore, generally as widely scattered microscopic grains within the galena, less commonly as larger, irregular grains associated with galena or sphalerite. The tetrahedrite is argentiferous, but because it is present in such small quantities in the ore, which ordinarily contains less than 0.01 per cent copper, it cannot have added much to the total silver content. As a little tetrahedrite

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occurs in fractures in the sphalerite or partly encloses small grains of sphalerite, it is younger than the sphalerite, but as it also forms irregular island-like inclusions in the galena, it is older than the galena.

Bournonite.—Bournonite ($Cu_2S \cdot 2PbS \cdot Sb_2S_3$) appears with the early as well as with the late group of minerals. The early bournonite is confined to widely scattered microscopic grains which form minute masses enclosed in galena, and, as in the Coeur d'Alene region,[6] narrow margins on tetrahedrite inclusions in galena. Some enclosed tetrahedrite is also cut by tiny veinlets and is also embedded by small grains of bournonite. These relations may at least in part indicate that the bournonite was formed during the replacement of tetrahedrite by galena; the tetrahedrite, which forms irregular island-like residua in the galena, contributed the copper, antimony, and some of the sulphur, and the lead-bearing solutions contributed the lead and perhaps a part of the sulphur. The position of bournonite in the sequence, therefore, is between tetrahedrite and galena; perhaps in part as a reaction rim between them. The younger generation of bournonite, as will be shown later, replaces the galena.

Pyrite.—Small remnant grains of pyrite are invariably present in the marginal parts of the ore bodies, and scattered crystals of it occur in the bordering wall rock. It is not conspicuous except in some of the fissure and breccia zones that were not impregnated with galena. It seems probable that deposition of some of the pyrite may have been associated with the wall-rock alteration, and that some may have accompanied the later sulphides.

The crystals and grains of pyrite are generally minute, but pyritohedral faces can usually be distinguished even on the smallest crystals. Crystal outlines are absent only where the mineral has been partly replaced by sphalerite, galena, and locally by the younger sulphosalts. Pyrite forms a few massive granular aggregates, but they are small and relatively inconspicuous. In zones of brecciated rock not filled with ore, it tends to form thin crystalline crusts on breccia fragments, much of it being in thin patches on the surface of the altered rock. Where it impregnates the wall rock it is in rather sparsely disseminated crystals.

As the pyrite has been engulfed in sphalerite and galena and locally replaced by them, it is clearly older than either; but it is younger than siderite, for in places pyritohedrons encrust crystal faces of siderite and are aligned along cleavage planes in the siderite. Locally pyrite and quartz are closely associated and one or both fill fractures in siderite or form veinlets replacing siderite. So little pyrite is enclosed in the galena as to suggest that in the main masses of ore, pyrite was almost entirely replaced by the younger ore minerals.

Arsenopyrite.—Arsenopyrite has been identified along all of the mineralized faults, but only in minute grains and crystals, which as a rule are sparsely disseminated so that the mineral can ordinarily be detected only under the microscope. It usually occurs in silicified walls bordering the ore seams, rarely as inclusions in the sphalerite and galena. Enough of it is associated

[6] Anderson, R. J.: Microscopic features of ore from the Sunshine Mine. ECON. GEOL., vol. 35, pp. 662–665, 1940. Willard, M. E.: Mineralization at the Polaris Mine, Idaho. ECON. GEOL., vol. 36, p. 595, 1941.

with the ore, however, to have appreciable effects on smelter returns, the arsenic content ranging up to 0.1 per cent in ore that has not been enriched in sulphosalts.

Much of the arsenopyrite forms minute rhombic crystals, but some of the crystals enclosed in sphalerite and galena have indented borders and rather irregular outlines. The crystals apparently were not so easily replaced as those of pyrite. Most of the arsenopyrite, like the closely associated pyrite, impregnated the bordering walls of the ore seams, lying alongside them rather than within them. The association of the arsenopyrite with equally minute crystals of pyrite in the wall rock suggests that both were deposited at about the same time and in advance of the other sulphides.

Siderite.—The siderite is an ever-present but not abundant mineral, being conspicuous in only a few places. It is generally very subordinate to the other minerals, probably because much of that which may have been deposited has been largely replaced by sphalerite and galena.

The siderite has a pale-buff color. It is manganiferous and yields a black gossan when oxidized. It exhibits a marked tendency to form regular crystals; perfect rhombohedra not uncommonly impregnate the sericitized wall rock and form crusts on rock fragments in breccias. In places these crusts are covered or partly covered by sulphides. The siderite also occurs in more massive form, particularly in stringers and irregular veinlets in the fractured wall rock and in thin sheets along walls of the ore seams. These sheets have generally been so brecciated by faulting movements and then so extensively replaced by the ore minerals that remnants are strewn along the marginal parts of the ore seams, forming small, bleblike inclusions, small discontinuous pods and interrupted layers, or more isolated grains. Siderite is therefore most conspicuous in veinlets and small bunches in the wall rock, beyond the reach of the sulphides.

The extensive replacement of the siderite by sulphides shows it to be an early mineral; it is in fact the earliest mineral in all deposits except one. In this exceptional instance it forms a layer on quartz, whereas elsewhere it is penetrated and replaced by quartz as well as by sulphides.

Quartz.—Quartz is considerably less abundant than siderite and ordinarily is not visible in the early-stage ore except in polished and thin sections. In some places, however, it forms small stringers and masses in the fractured wall rock and small crystals and grains within the ore itself. Veinlets and irregular masses are composed of white granular quartz; crystals also are white. In some places the crystals form drusy crusts on breccia fragments of the wall rock, but in ore bodies the crystals are isolated and enclosed by sulphides.

At the Ralph property just east of the Lawrence mine two generations of quartz have been recognized, one earlier than the siderite and one later. In this exceptional occurrence the quartz-encrusted fragments of country rock are coated by siderite, and the siderite in turn is covered with quartz; but elsewhere throughout the district the quartz has been deposited on siderite crystals or in stringers or irregular patches that cut and replace the siderite as well as the country rock. For the most part, the quartz is older than the sulphides,

for remnant grains and crystals of it are enclosed in the sulphides and patches and stringers are cut and replaced by ore. Although deposition of much of the quartz apparently preceded the deposition of early sulphides, the presence of isolated quartz crystals in the galena suggests that some quartz also was deposited with the ore minerals.

Barite.—Barite is exceedingly rare, having been noted in only two places, one as a filling less than an inch thick between walls of coarse white comb quartz, the second as scattered microscopic crystals in or near seams or stringers of quartz in silicified wall rock. Its relations prove it to be younger than quartz, but there is nothing to indicate its age with respect to the sulphides. Since it is closely associated with the quartz, it may, like the quartz, have been deposited before the sulphides.

Calcite.—Calcite, though it generally escapes notice, is more or less widely distributed through the district, chiefly in microscopic stringers that cut the sulphides. At one place tiny flat rhombohedrons encrust sulphides and in another place crystalline crusts as much as a fourth of an inch thick occupy fractures in galena; but elsewhere the calcite was recognized only microscopically as fracture fillings in the sulphides, with such relations as to indicate that it is the youngest of the early-stage minerals, having apparently been deposited just after the last of the galena.

Rhodochrosite.—Rhodochrosite occurs sparsely in little stringers of no great persistence along some minor slips in the Hope mine. As it was not observed in contact with the ore, its position in the depositional sequence is in doubt.

LATE MINERALS (HYPOGENE-ENRICHMENT STAGE).

General Features.—Most of the sulphantimonites and sulpharsenites that make up the late additions to the ore form lead-gray to steel-gray granular masses, which may easily be mistaken for tetrahedrite except in a few places where they form fibrous and divergent groups. These younger minerals occur for the most part as irregular veinlets and bodies in the galena, especially in deformational zones near and along the margins of the ore seams. Stringers of them also penetrate and replace fractured siderite, and masses of them cement the marginal sphalerite, apparently in part by replacing the galena that previously had cemented the sphalerite. This latter relationship is suggested where remnants of the galena remain in the sulphosalts that cement the sphalerite. Deposition, however, has not been effected by replacement alone; stringers have been observed along some of the fault zones that contain but little galena. Some of the ore in one part of the Whitedelf mine is made up of curved laths and needles of sulphosalts that penetrate and lie between crystals of quartz.

The late minerals are visible throughout the Hope mine; in places they make up fully a third of the ore. They are even more abundant at the Whitedelf mine. On upper levels of the Whitedelf they made up from a tenth to a fourth of the ore, but with depth the proportion of sulphantimonites and sulpharsenites seemed to increase and in places these minerals made up more than half of the ore. In the southwest ore shoot (Fig. 2), the ore consisted

almost entirely of sulphosalts. This shoot was about 130 feet long; it contained up to 3 feet of high-grade ore, in bunches and compact seams and patches, and up to 6 feet of milling-grade ore. Small amounts of the late minerals have also been observed in a number of slightly mineralized faults near the Hope and Whitedelf mines, but none have been found at the Lawrence mine nor at immediately adjacent properties.

The late minerals that may readily be recognized include quartz and pyrargyrite; the others are so much alike that they can be distinguished only in polished sections and identified only by etch and microchemical reactions. The complete list of minerals includes quartz, boulangerite, geocronite, meneghinite, semseyite, jordanite, guitermanite, bournonite, freieslebenite, pyrargyrite, and possibly tetrahedrite. Identification was based on etch and microchemical tests outlined by Short.[7] Although mostly indistinguishable from galena without etching or without resorting to polarized light, they stand out vividly when the section is etched lightly with hydrochloric acid or with ferric chloride. Some which react to hydrochloric acid respond so slowly to a quick etch that they are easily separated from the galena. All are etched by nitric acid but the freieslebenite and bournonite react so slowly that they may remain as light gray or galena-white veinlets after the others have become blackened or made iridescent. Most of the minerals have fairly distinctive polarization colors which prove useful for identification. A table summarizing the distinctive etch reactions and polarization colors is given (Table 1).

Quartz.—Quartz belonging to the hypogene enrichment stage was relatively abundant only in the ore shoot composed almost entirely of various sulphosalts at the Whitedelf mine. There it formed rather loosely meshed, partly interlocking crystals cemented and in part penetrated by needles and laths of sulphantimonites and sulpharsenites. It forms a very subordinate part of the ore shoot as a whole, and it seems to be absent except for occasional microscopic crystals from all the other deposits in the district.

Boulangerite.—Boulangerite ($5PbS \cdot 2Sb_2S_3$) appears to be the most abundant of the sulphosalts at the Whitedelf mine but is present in almost negligible quantities at the Hope mine. In polished sections its galena-white color makes it very difficult to distinguish from galena except with the aid of polarized light, when it gives rather strong almost white, gray, dark-gray, brownish-gray and steel-blue polarization colors. These colors tend to set it apart from the other sulphosalts, except semseyite, which has somewhat similar polarization colors but otherwise is light gray rather than galena-white and has a more finely granular structure. The boulangerite is only slightly tarnished by hydrochloric acid fumes, and, although it tends to effervesce with nitric acid and turn black, the action is slow in starting.

Some of the boulangerite forms stringers less than an inch thick in the country rock, but most of it is in irregular seams, bunches, and stringers from a fraction to an inch or more thick that replace galena, or as veinlets along galena contacts.

[7] Short, M. N.: Microscopic determination of the ore minerals. U. S. Geol. Survey Bull. 914, 1940.

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TABLE 1.

ETCH REACTIONS AND POLARIZATION COLORS OF THE SULPHO-MINERALS.*

Mineral	Composition	Hardness	Color	Polarization Colors	HNO_3	HCl	Miscellaneous
Geocronite	$5PbS \cdot Sb_2S_3$	B	Gray	Pinkish brown, steel blue	Eff. black	Fumes may tarnish slightly but no staining	Has greenish tinge in contact with galena
Jordanite	$4PbS \cdot As_2S_3$	C	Galena white	Light gray, pinkish gray, violet, dark gray	Slow starting, then gray to brown	Negative	
Meneghinite	$4PbS \cdot Sb_2S_3$	C−	White	Strong light gray, pinkish brown, steel blue	Eff. black. Slow starting †	Fumes tarnish slightly. Long etch develops structure	Microchemical tests for Cu. Distinctive
Guitermanite	$3PbS \cdot As_2S_3$	C	Galena white	Reddish brown, steel blue	Eff. slowly and stains iridescent	Negative	
Boulangerite	$5PbS \cdot 2Sb_2S_3$	B+	Galena white	Strong white, steel blue, brownish gray, dark gray	Eff. black. Slow starting	Fumes tarnish some areas slightly	
Semseyite	$9PbS \cdot 4Sb_2S_3$	C	Gray	Strong light gray, bluish gray, brown, dark gray	Eff. black	Fumes tarnish slightly. Surface stains	Very slowly iridescent with KOH
Bournonite	$Cu_2S \cdot 2PbS \cdot Sb_2S_3$	C−	Gray	Greenish gray, dark brown, purple	Some areas light brown after long etching. Fumes tarnish slowly	Negative	
Freieslebenite	$2Ag_2S \cdot 3PbS \cdot 2Sb_2S_3$	C	Galena white	Light gray, brownish gray, dark gray	Some areas very slightly after long etching. Mostly negative	Negative	
Pyrargyrite	$3Ag_2S \cdot Sb_2S_3$	C	Bluish gray	Light gray, steel gray, brown. Some reddish internal reflection	Fumes tarnish	Fumes slowly tarnish, halo does not wash off	Usual reactions to KCn, KOH, and $HgCl_2$

* Minerals are negative to KCn, $FeCl_3$, KOH, and $HgCl_2$ unless otherwise specified.
† Once started the etching rapidly advances as a wave from one side of drop to the other.

Meneghinite.—Meneghinite ($4PbS \cdot Sb_2S_3$) seems to be the most abundant of the sulphosalts at the Hope mine but it is sparingly present at the Whitedelf. Its white color in polished sections makes it impossible to distinguish from galena and boulangerite, despite its slightly greater hardness, but with polarized light its prominent light-gray, pinkish-brown and steel-blue polarization colors make it outstanding, particularly because the polarization colors are stronger than those of boulangerite.

Ordinarily it shows little response to hydrochloric acid, although fumes may produce a slight tarnish, but when the acid is warmed slightly, the mineral develops a distinctive more or less concentric etch pattern as shown in Figs. 3 and 4. It effervesces with nitric acid and turns black. The action is slow in starting but when started advances rapidly as a wave from one side of the drop to the other (according to Short a distinctive property).[8] It gives a microchemical test for copper, which, according to Short, is also a distinctive test.

Like the boulangerite the meneghinite forms veinlets and masses in the galena and may retain residual inclusions of galena and inclusions of pyrite and sphalerite inherited from the galena. Its relations to boulangerite are not altogether clear but small masses or seams isolated or cut off by the boulangerite may suggest that it is the oldest of the two. As it engulfs and penetrates geocronite, it must be younger than geocronite.

Geocronite.—Geocronite ($5PbS \cdot Sb_2S_3$) is fairly abundant at both the Hope and Whitedelf mines, though subordinate to meneghinite and boulangerite. It is the only sulphosalt, except pyrargyrite, that can be distinguished in polished sections without etching or without polarized light. It is not as white as most of the other sulphosalts but it stands out in polished sections mainly because in contact with galena it has a decided greenish tinge which affords enough contrast so that the two may be distinguished in photomicrographs without etching the galena (Fig. 5). Its polarization colors are rather distinctive, being deep pinkish or reddish brown and pronounced steel blue. Its surface is slightly tarnished by hydrochloric acid fumes but the reaction is not always clearly defined. It responds quickly to nitric acid, effervescing and rapidly becoming black.

Most of the geocronite was observed in masses and as veinlets and stringers penetrating and replacing galena (Fig. 6). Some of the masses isolated by boulangerite and meneghinite suggest that the geocronite had formed ahead of the other two.

Semseyite.—Semseyite ($9PbS \cdot 4Sb_2S_3$) was observed only in the ore from the sulphosalt-rich ore shoot (Fig. 2) at the Whitedelf mine where it was rather intimately associated with boulangerite and guitermanite. In polished sections the semseyite is light gray rather than white. Except for this slight difference in color and the fact that it becomes slowly iridescent after long etching with potassium hydroxide, it is similar to the boulangerite. Its reaction to hydrochloric and nitric acids is the same as for boulangerite, but its polarization colors differ slightly, showing less of the white and steel-blue colors and more of the grayish and brownish colors. It also has a rather fine

[8] Idem, p. 117.

granular texture (visible in polarized light) which tends to set it apart from the more coarsely crystalline and lath-like boulangerite.

Some of the finely granular semseyite cuts through the boulangerite in such a way as to resemble zones of finely granulated boulangerite. Such re-

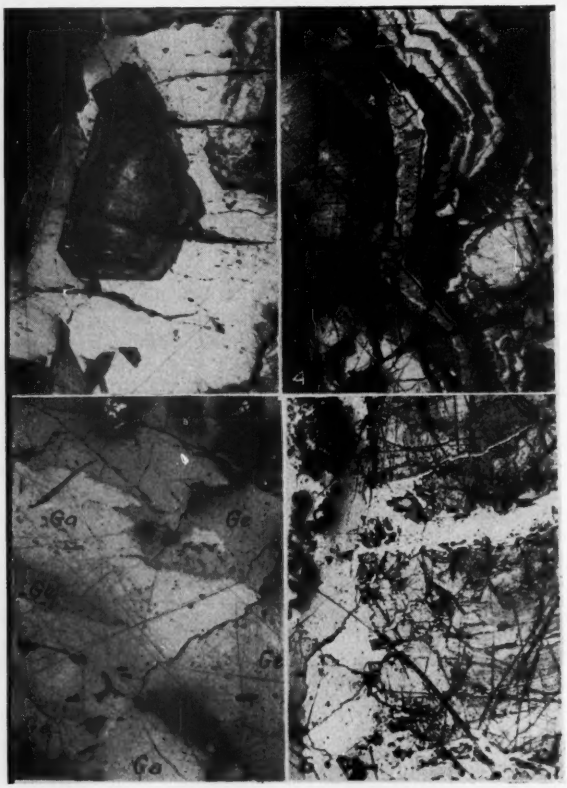

FIG. 3. Peculiar etch pattern developed in meneghinite by action of warm hydrochloric acid. Both the etched and unetched (white) surface is meneghinite. × 110.

FIG. 4. Another etch pattern developed in the meneghinite by the action of hydrochloric acid. × 110.

FIG. 5. Unetched surface showing the slightly darker geocronite (Ge), with inherited inclusions of pyrite (Py), penetrating into and replacing galena (Ga). × 110.

FIG. 6. Geocronite veinlets (white) penetrating and replacing galena which has been etched with dilute hydrochloric acid to bring out the flowage structure. Small crystals of quartz (Q) mostly contemporaneous with the geocronite show in the section. × 110.

lationships suggest that the semseyite is somewhat younger than the boulangerite and that it replaces the boulangerite.

Jordanite.—A small amount of jordanite ($4PbS \cdot As_2S_3$) was identified in some of the ore from the southwest shoot at the Whitedelf mine that consisted almost entirely of sulphosalts. Its presence perhaps explains in part the increased arsenic content of the ore shipped from that body in 1940, when the shipments contained twice as high a percentage of arsenic as those of other years. The jordanite, though slightly harder, closely resembles boulangerite in polished sections but possesses distinctive though rather weak light-gray, pinkish, violet, and dark-gray polarization colors. It is slow in its reaction to nitric acid but when action starts the surface quickly turns gray to brown. It does not seem to be affected by hydrochloric acid or its fumes.

Most of the grains and masses of jordanite were isolated, but a few were intimately associated with guitermanite. Its relations to other sulphosalts is unknown.

Guitermanite.—Guitermanite ($3PbS \cdot As_2S_3$) is more abundant than jordanite but is one of the minor minerals, apparently confined to the sulphosalt-rich shoot at the Whitedelf mine. It is probably largely responsible for the increased arsenic content of the ore shipped from that shoot. It has the same hardness and color as the jordanite, appearing in galena-white grains and masses in polished sections, but its polarization colors—reddish brown and steel blue—are quite distinctive, also its reaction to nitric acid with which it acts slowly and stains iridescent. It is the only mineral other than tetrahedrite that stains iridescent with nitric acid.

As shown in Fig. 7, it forms some fairly pure masses where it is isolated or protected from other sulphosalts but otherwise it appears to be intimately associated with or penetrated by semseyite or boulangerite, as though in part replaced by them.

Bournonite.—Bournonite ($Cu_2S \cdot 2PbS \cdot Sb_2S_3$) reappears with the younger minerals in the ore at the Hope and Whitedelf mines, but only as a very minor constituent. It becomes visible microscopically when the associated minerals have been etched by nitric acid. Although bournonite itself reacts to nitric acid, it does so very slowly and the effects (a light tarnish by the fumes and a weak brownish staining by the liquid) are so slight that the light colored veinlets stand out conspicuously in the highly etched galena and the other sulphosalts. Its polarization colors—greenish gray, dark brown, and purple—are fairly distinctive, but as much of the mineral forms minute stringers and few large masses, the polarization colors are rarely striking and the bournonite is difficult to distinguish from freieslebenite, which has weaker and different polarization colors.

This younger generation of bournonite may be responsible for the high copper content of the ore at both the Hope and Whitedelf mines. In the latter mine, most of the ore shipped between 1939 and 1941 inclusive contained from 0.01 to as much as 0.5, and some of it contained as much as 0.8 per cent copper, whereas the ore shipped earlier contained less than 0.01 per cent copper. The increase came when ore notably rich in the sulphosalts was mined. The ore at the Hope mine likewise has fluctuated between 0.01 and 0.2 per

cent copper. The ore at the Lawrence mine, on the other hand, has never contained more than 0.01 per cent copper; that minute quantity probably represents the percentage of copper in the ore deposited throughout the district during the early stages of mineralization, any greater amount being due to enrichment during the later hypogene stage.

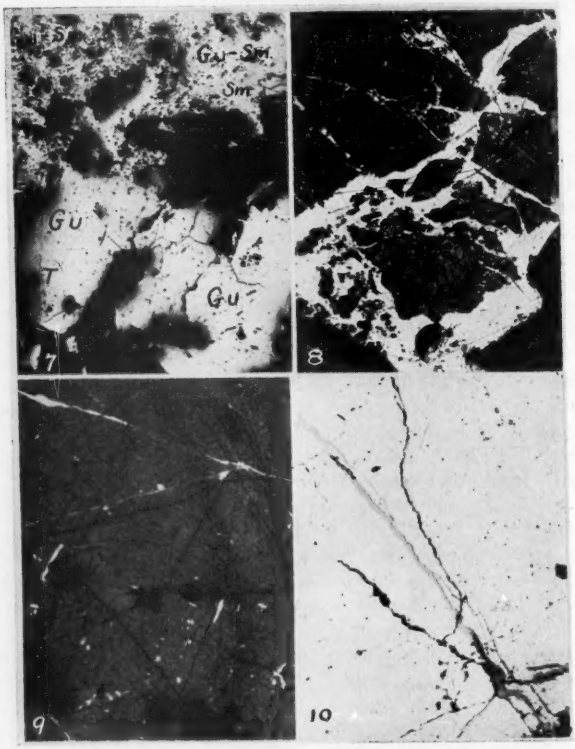

FIG. 7. Guitermanite (Gu) largely enclosed and protected by quartz crystals (black) merging with an intimate mixture of guitermanite and somewhat darker semseyite (Gu and Sm). The intimate association of the guitermanite and semseyite apparently has resulted from the penetration of and the partial replacement of the guitermanite by semseyite. A rounded grain of tetrahedrite (T) shows near the edge of the main body of guitermanite. × 110.

FIG. 8. Veinlets of freieslebenite (white) cutting and replacing boulangerite, revealed by etching the surface of the polished section with nitric acid. Grayish black quartz shows along one side and end of the photomicrographs. × 110.

FIG. 9. Small veinlets and grains of freieslebenite in meneghinite revealed by etching the surface of the polished section with nitric acid. × 110.

FIG. 10. Veinlet of pyrargyrite (light gray) penetrating and replacing galena (white) along a fracture. × 110.

Tetrahedrite.—Occasional microscopic grains of tetrahedrite have been observed as inclusions in sulphosalts, in part as grains inherited from the early-stage galena mineralization, in part, particularly in the sulphosalt-rich ore shoot at the Whitedelf mine, as grains possibly deposited during the stage of hypogene enrichment. One such small grain inclusion is shown near the border of the main mass of guitermanite in Fig. 7. A few larger grains have been observed in more isolated parts of the younger-stage quartz, less closely associated with the sulphosalts.

Freieslebenite.—Freieslebenite ($2Ag_2S \cdot 3PbS \cdot 2Sb_2S_3$) occurs as microscopic stringers and grains in the ore at both the Hope and Whitedelf mines. Because of its galena-white color in polished sections it cannot be distinguished from galena and the various sulphosalts until the minerals associated with it have been blacked out by etching with nitric acid. The freieslebenite is negative to nitric acid or is only lightly stained at the most and it therefore stands out, as shown in Figs. 8 and 9, as whitish veinlets cutting and replacing the sulphosalts. The veinlets are generally not so large nor so closely spaced as those shown in Fig. 8 but are more widely scattered through the other minerals, more like the veinlets and grains shown in Fig. 9. Except in very local occurrences, the freieslebenite is considerably more abundant than the rather closely associated bournonite, which it tends to resemble but from which it differs in its light-gray, brownish-gray and dark-gray polarization colors.

Although the freieslebenite is visible only under the microscope, it is apparently one of the most important of the ore minerals in the district, and it may be the source of a large part of the silver production at the Hope and Whitedelf mines. The ore at the Lawrence mine, which does not contain this mineral, averages about 15 ounces of silver to the ton of concentrates. These concentrates, which average 75 per cent lead, appear to contain the silver in argentiferous galena, which had only sparse microscopic inclusions of tetrahedrite. On the other hand, the concentrates at the Hope mine, which average less than 70 per cent lead but carry appreciable amounts of freieslebenite, contain 2 to 3 times as much silver as the concentrates at the Lawrence, whereas the concentrates at the Whitedelf mine contain 3 to 4 times as much silver as those at the Lawrence. In 1940 and 1941 the silver-lead ratio at the Whitedelf was somewhat higher still—probably not because of any material increase in the amount of freieslebenite but because of the presence of pyrargyrite.

Pyrargyrite.—Pyrargyrite ($3Ag_2S \cdot Sb_2S_3$) has thus far been observed only at the Whitedelf mine, and there only in the southwest ore shoot composed almost entirely of sulphosalts. It is fairly abundant in this ore shoot, where it is plainly visible in places as scattered grains and irregular stringers in the ore, particularly along fractures that cut the masses of lead sulphosalts and galena. In polished sections it is easily detected without etching, for it shows as grains and veinlets cutting across and replacing the various sulphosalts and galena (Fig. 10). As it is not so intimately associated with the group of sulphantimonites and sulpharsenites as is freieslebenite and as it has been found not far beneath a steep ridge slope where ground water circulation is possible, it may be supergene.

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The presence of pyrargyrite markedly increases the silver content of the ore in which it occurs. Through much of the Whitedelf mine the silver-lead ratio has been about one ounce of silver to each per cent of lead, but in the shoot that contains the pyrargyrite the ratio commonly ranges from 2:1 to 3:1 and goes as high as 6:1. The last two shipments of concentrates in 1941 contained 210.5 and 237.5 ounces of silver to the ton and 38.6 and 36.6 per cent lead respectively.

PARAGENESIS.

Since many data on mineral succession have been included in the descriptions of the individual minerals, little more than a summary of the paragenesis need be given. The order in which the minerals were deposited during the early (Coeur d'Alene) stage of mineralization is particularly well defined, for wherever the minerals were not deposited as successive crusts in open spaces, minor faulting contemporaneous with ore deposition fractured and crushed the earlier minerals, which were then cemented and partly replaced by later minerals. During the second (hypogene-enrichment) stage of deposition, the combination of mineralization and repeated faulting was not so prominent; the order in which the various sulphosalts were deposited is therefore not so easily interpreted. A summary of the paragenetic sequence of the minerals in the ore is given in Table 2.

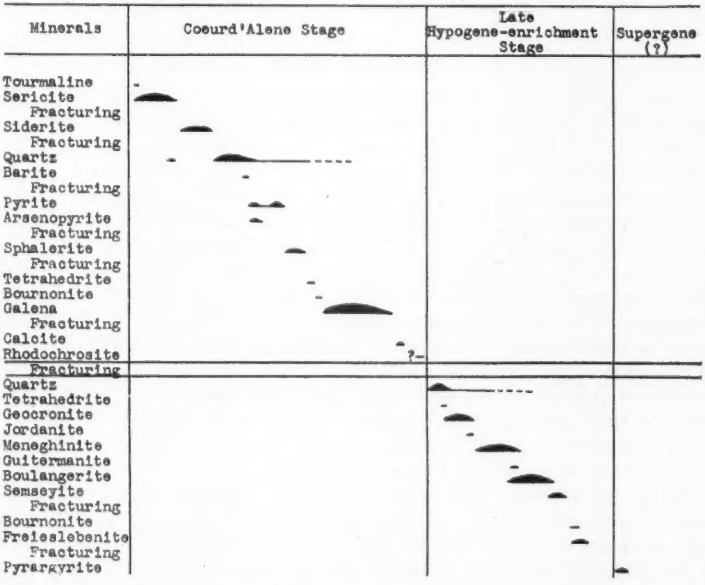
In all of the principal deposits mineralization was initiated by deposition of siderite in fractures, accompanied by replacement of the bordering country rock, which prior to this had been rather extensively sericitized by the mineralizing solutions. A period of minor faulting followed before other minerals were introduced. Much of the siderite that had been deposited, except that in the walls, was more or less extensively brecciated by this faulting, after which quartz and then sulphides were brought in, all of which replaced the siderite except where the siderite had only partly filled open spaces and had not been appreciably disturbed by the mineralization faulting; in those places the quartz and sulphides were deposited on the surface of the siderite crystals. A minor structural break intervened between the deposition of quartz and that of the sulphides, for much of the quartz is cut by fractures filled with sulphides, and part of the quartz is replaced by sulphides. Quartz continued to be deposited with the sulphides and is enclosed in the sulphides as widely scattered crystals. Barite was locally deposited in the quartz, perhaps before the sulphides.

The first sulphide deposited, perhaps during late stages of wall-rock alteration, was either pyrite or arsenopyrite; there is no decisive evidence as to which was first. Pyrite was again introduced as the first mineral of the main sulphide stage of deposition, but before the other sulphides were deposited it was fractured. The later and the earlier pyrite and arsenopyrite were cemented and partly replaced by the sulphides that followed—first sphalerite and later galena. Before galena was deposited, however, the sphalerite, except where it entered and was protected by the walls, was shattered by recurrent movement so that in places it is now strewn through the galena in unoriented, in part replaced fragments. Tetrahedrite was deposited after sphalerite, but

much of it was subsequently replaced by galena, locally with an intervening rim of bournonite. Very minor fracturing of the galena and other minerals permitted the introduction and deposition of a little calcite. Whether the rhodochrosite was introduced at this point or during the succeeding silver-antimony stage was not determined. In any event since the calcite cuts all galena deposits, its deposition probably marked the close of the early-stage mineralization. Renewed faulting further shattered the sphalerite and de-

TABLE 2.

PARAGENETIC SEQUENCE OF THE MINERALS IN THE CLARK FORK ORES.



formed the galena by flowage, giving much of it a prominent banded or gneissic structure or changing it to fine-grained "steel galena."

A more severe structural disturbance reopened the deposits at the Hope and Whitedelf mines and permitted introduction of minerals of the hypogene-enrichment stage. This disturbance, however, did not materially affect the deposits at the Lawrence and adjacent mines. The early ore at the Hope and Whitedelf mines was fractured, especially the ore next to the walls, and new fissures were formed. The reopening at the Whitedelf mine was more pronounced than at the Hope mine. At least in one place quartz was the first mineral deposited during the renewed mineralization, but generally the various complex sulphantimonites and sulpharsenites were deposited with little, if any quartz. Because mineralization movements were not so prevalent as during the earlier Coeur d'Alene stage, the sequential relations are not so dis-

tinctly defined and in part are rather obscure. These younger minerals filled fractures and replaced galena. Some sulphantimonites and sulpharsenites replaced other sulphantimonites and sulpharsenites, but some associations are so intimate that they may denote simultaneous deposition. The first of the sulphosalts to be deposited may have been tetrahedrite, but the first of the lead sulphosalts was geocronite, followed by meneghinite and perhaps jordanite and guitermanite, then by boulangerite and semseyite, apparently in order of decreasing lead content. Weak fracturing after the semseyite had been deposited permitted bournonite and freieslebenite to replace the other minerals along well-defined veinlet systems. Still later fracturing controlled deposition of pyrargyrite, which, however, may have been introduced by supergene rather than by hypogene solutions.

MINERAL ZONING.

Some tendency toward both horizontal and vertical zoning of minerals, part of which may be accounted for on thermal and part on structural grounds, is shown by the deposits in the district. The horizontal zoning is not especially well displayed within any single deposit except the Whitedelf (Fig. 2) but it becomes apparent when the deposits are considered collectively. Sphalerite, for example, is more plentiful in the Hope and Whitedelf mines than in the Lawrence; galena, on the other hand, is proportionately more abundant in the Lawrence than in either the Hope or Whitedelf. Where it is relatively scarce, the fact is largely due to its having been in part replaced by the lead sulphosalts. As the sulphosalts contain less lead than galena, the concentrates at the Whitedelf mine, where sulphosalts are most abundant, contain less lead than those at the Lawrence mine, where sulphosalts are lacking. On the other hand, the concentrates at the Lawrence mine carry much less silver and very little antimony, both of which are high at the Whitedelf.

Horizontal zoning has been dependent on local fracturing which was most intense at the Whitedelf and least so at the Lawrence. Apparently the deposits at the Whitedelf and Hope mines were reopened by faulting just in time to receive the solutions bearing silver and antimony, and, as the disturbance was more marked at the Whitedelf mine than at the Hope, the reopening at the Whitedelf was more complete and the channels formed were more favorable for the circulation of the ore-forming solutions. The Whitedelf deposits consequently received more of the sulphosalts while the Lawrence deposit received none at all.

Vertical zoning seems to be shown in each of the deposits, though at the Lawrence mine the inaccessibility of the lower workings made it impractical to gather much evidence bearing on this point. At both the Hope and Whitedelf mines, sphalerite appears to be somewhat more abundant at depths of several hundred feet, whereas galena tends to become somewhat less abundant, largely because of an increase in sulphosalts. There is a corresponding decrease downward in the percentage of lead, particularly at the Whitedelf (Fig. 2) where the sulphosalts are most abundant, and a proportionate increase in the amount of silver and antimony. The material gain in silver and antimony with depth at the Whitedelf mine may be explained on the supposition that these two elements were largely deposited by replacement of galena before the

solutions that carried them reached what are now the upper levels of the mine. Whereas early shipments from upper levels of the mine contained around 60 per cent lead and 60 ounces of silver per ton, the ore from the lower levels contained between 35 and 40 per cent lead and more than 200 ounces in silver.

GENESIS.

Localization of dikes of diabase and granodiorite, quartz monzonite, granite, and rhyolite porphyry and the lead-silver deposits along the zone of structural weakness controlled by the Hope fault indicates a close relationship between faulting, intrusion, and mineralization. As intrusion and mineralization took place while faulting was still in progress, the faulting must have reached a relatively deep magma reservoir and provided avenues of escape for portions of a differentiating magma and later for mineralizing solutions.

The escape of mineralizing solutions from the magmatic source was repeatedly disturbed by structural adjustments, some of them small, some of them rather large. When the solutions first reached the levels at which the ore is now found, they apparently were rich in potash. They reacted strongly with the country rock in and along the zones of faulting, extracting lime and silica and depositing potash, which combined in sericite as the main product of reaction. The mineralizing process may then have been temporarily interrupted by renewed faulting. The successive solutions that rose subsequently differed in composition from the earlier ones, as already shown in the paragraph on paragenesis. At first they carried considerable amounts of ferrous iron and carbonates, later silica, accompanied locally by a little sulphate (barite) and were succeeded in turn by solutions bearing the various metals.

The absence of minerals diagnostic of high-temperature origin (apart from occasional crystals of tourmaline in the wall rock) indicates that temperatures of the mineralizing solutions while the minerals were being deposited never rose above moderate heights, perhaps not above 300° C.[9] Sericite, siderite, and quartz in the country rock are commonly associated with mesothermal deposits, and the ore minerals of the early stage of mineralization are also such as are deposited at mesothermal temperatures. During the second stage, however, the temperatures must have been appreciably lower, for silver and antimony generally become more concentrated as the temperature of the solutions becomes lower; the complex sulphantimonites and sulpharsenites are commonly regarded as diagnostic of epithermal or low temperature deposition.

ACKNOWLEDGMENTS.

The writer wishes to acknowledge his indebtedness to F. C. Calkins, E. T. McKnight, Charles Park and G. F. Loughlin of the U. S. Geological Survey, for their suggestions and constructive editorial assistance in the preparation of the report.

DEPARTMENT OF GEOLOGY,
CORNELL UNIVERSITY,
ITHACA, NEW YORK,
November 23, 1945

[9] Lindgren, Waldemar: Mineral Deposits, 4th Ed., p. 529, 1933.

SEDIMENTARY AND VOLCANIC PROCESSES IN THE FORMATION OF HIGH ALUMINA CLAY.*

VICTOR T. ALLEN.

ABSTRACT.

In the West, where volcanic materials are abundantly distributed among the rocks of the geologic column, the importance of sedimentary processes in the formation of high-alumina clays has not been fully appreciated. At Ione, Calif., Castle Rock, Wash., Whiteware, Mont., Hobart Butte and Mollala, Oreg., where the Geological Survey has been investigating clays jointly with the Bureau of Mines, U. S. Department of the Interior, high-alumina clays formed by sedimentary processes are more important than those formed by all phases of volcanic activity. Clays derived directly from volcanic materials are composed dominantly of montmorillonite; but these clays, with the exception of the beidellite-nontronite varieties, have relatively low percentages of available alumina. In contrast, clays derived by thorough leaching of various aluminous rocks under conditions favoring thorough drainage are composed dominantly of kaolinite and when sorted by sedimentary processes form high-grade deposits; furthermore, the depositional structures of these sedimentary clays have favored the derivation of gibbsite through weathering, resulting in an increase in the alumina content of the clays. Kaolinite, gibbsite, and dickite all have relatively high percentages of available alumina.

INTRODUCTION.

In connection with the investigation of high-alumina clays in the Pacific Coast States by the Geological Survey, U. S. Department of the Interior, it has been noted that statements in the literature repeatedly connect the origin of these clays with volcanic processes. The purpose of this paper is to examine the geologic history of five western clay deposits which have been explored jointly by the Geological Survey and the Bureau of Mines, U. S. Department of the Interior, and evaluate the effects of sedimentary and volcanic processes at these localities.

IONE CLAY DEPOSIT, AMADOR COUNTY, CALIFORNIA.

A notable example of a sedimentary clay formation being mistaken for altered volcanic material is the Ione formation of California. This formational name was given by Lindgren[1] in 1892 and applied to the pottery clays at Lincoln that contain a few seams of inferior lignite. Similar clays were reported by him to extend southward from Lincoln towards Ione, to occur below andesitic detritus, and to show at many places indications of being derived

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[1] Lindgren, W.: U. S. Geological Survey, Sacramento Folio 5: 3, 1894.

from rhyolitic tuffs. In 1894 Turner [2] made three divisions of the Ione formation at the type locality: (1) white clays and sands containing lignite, forming the lowest member; (2) white or red sandstone, (3) "Clay rock" or tuff. The clays of the lowest member were considered by Turner and later writers as altered rhyolitic tuffs. In 1929 restudy of the Ione formation by Allen [3] restricted the Ione formation to the lower two members of Turner and established, below the andesitic breccias at Ione and Lincoln, two clay series differing in mineral composition and origin and separated by an erosional unconformity. The lower clays at Lincoln, containing lignite seams, are composed of kaolinite, are of sedimentary origin and belong to the Ione formation of Eocene age. The clays above the disconformity are composed of montmorillonite, are in part altered rhyolitic ash and belong to the rhyolitic period of the Oligocene or early Miocene. The "Clay rock" originally considered as the uppermost member of Turner's type Ione is an altered rhyolitic tuff and is separated from the lower two members by a disconformity. It belongs to the rhyolitic period and not in the Ione formation. Its chief clay mineral is montmorillonite, which has low available alumina,[4] ranging from 7 to 20 per

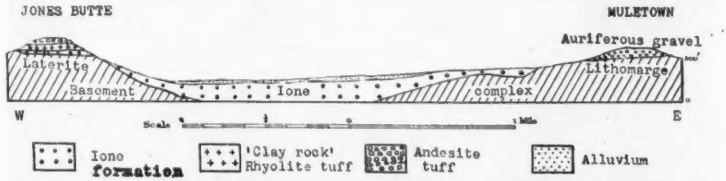

FIG. 1. Cross section two miles north of Ione showing relationship of the Ione formation to the auriferous stream gravels to the east, to the underlying weathered mantle and to the volcanic materials disconformably overlying it.

cent in samples tested by the U. S. Bureau of Mines. The clays of the lowest member of the Ione formation are composed of kaolinite-anauxite, some of which is present as books. Moreover, these clays lack volcanic textures and have relatively high available alumina, 32 to 36 per cent in samples free from quartz. It was this horizon which was explored by a joint Geological Survey —Bureau of Mines drilling project. The sandstone member of the Ione formation contains books of anauxite interbedded with quartz. At the Buena Vista quarry south of Ione the uppermost horizontal layer of this sandstone contains casts of marine Eocene fossils and overlies channel sandstones with fluvial bedding and scour and fill structures such as are formed at the distributaries of deltas. The high-alumina clays of the Ione district are sedi-

[2] Turner, H. W.: Rocks of the Sierra Nevada. U. S. Geol. Survey, Fourteenth Ann. Rep., pt. II: 462–465, 1894.

[3] Allen, Victor T.: The Ione formation of California. Univ. Calif. Pub., Bull. Dept. Geol. Sci. 18: 353, 1929.

[4] According to the Bureau of Mines, U. S. Department of the Interior, available alumina is the percentage of alumina that can be extracted with 20 per cent H_2SO_4 from the clay after heating it to 700° C. It is based on the weight of the clay dried at 130° C. For a clay to be considered a high-alumina clay ore, it should contain more than 20 per cent available alumina.

mentary accumulations of kaolinite-anauxite deposited as deltas by westward-flowing Eocene streams that deposited the pre-volcanic auriferous gravels on the slopes of the Sierra Nevada to the eastward (Fig. 1). At many places the Ione formation rests on a weathered surface that is a remnant of the once extensive weathered mantle from which the clays of the Ione formation were derived. The clay minerals in this residual pre-Ione mantle are similar to

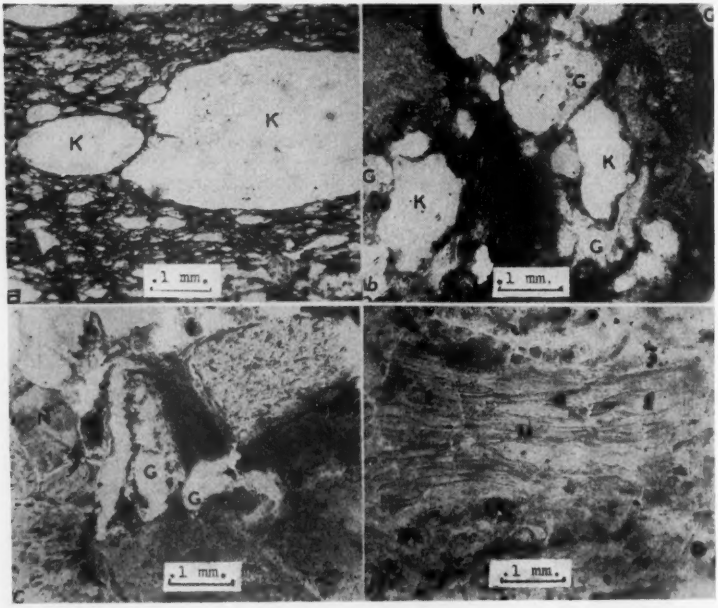

FIG. 2. a. Kaolinite pellets (K) surrounded by fine clay and organic material. Available alumina 32%. Castle Rock, Washington.

b. Grains of volcanic rocks altered to kaolinite (K). Gibbsite (G) formed along edges of grains. Available alumina 42%. Castle Rock, Washington.

c. Grains of volcanic rocks altered to nontronite (N). Gibbsite (G) formed along edges of grains. Available alumina 30%. Castle Rock, Washington.

d. Pumice fragment (M) altered to montmorillonite. Available alumina 5%. Castle Rock, Washington.

those in the Ione formation. Sorting of the clay minerals from this mantle by sedimentation was the only action required to form the high-alumina clay of the Ione formation.

COWLITZ CLAY DEPOSIT, NEAR CASTLE ROCK, WASHINGTON.

Near Castle Rock, Cowlitz County, Washington, 60 miles north of Portland, Oregon, is an unusual deposit of high-alumina clay. The only kind of

pellet structure [5] recorded as occurring in this clay consists of rounded pellets of white fine-grained volcanic ash. This gives one the impression that all the pellets in the clay near Castle Rock are composed of volcanic detritus. At the open pit where refractory clays are being mined by the Gladding McBean Company, pellets of kaolinite are surrounded by organic materials outlining bedding that is parallel to the associated lignite (Fig. 2 a). Similar pellets are common in the "Coal Measures" fire clays of Eastern United States and are composed of clay particles of sedimentary origin. Other beds at the Castle Rock deposit are made up of silt and sand size fragments of rocks, chiefly andesite, that have been altered in place to clay minerals and to gibbsite. As gibbsite occurs around the boundaries of the grains and cuts the

GENERALIZED SECTION In part from U. S. Bureau of Mines cores	ROCK TYPES	CLAY MINERALS	Available alumina Courtesy of U. S. Bureau of Mines
	Basalt		
	Clay, dark gray or green Locally lignitic	Beidellite-Montronite Locally - some gibbsite Locally - montmorillonite	18 - 30%
	Clay, light gray with subordinate lignite Pellet structure common Sand-silt textures often preserved	Kaolinite - Halloysite $Al_2O_3.2SiO_2.2H_2O$ - $Al_2O_3.2SiO_2.2H_2O$	30 - 42%
	Gibbsite at margins of and cutting pellets and sand grains Siderite in tiny nodules in all clay types	Gibbsite - $Al_2O_3.3H_2O$ Later than kaolinite pellets	
	Sand, Silt or Clay: Volcanic rock fragments chiefly andesites altered since deposition	Beidellite - Montronite $Al_2O_3.3SiO_2.nH_2O$ - $Fe_2O_3.3SiO_2.nH_2O$	21 - 30%
	Sand, Silt or Clay: Volcanic rock fragments chiefly rhyolites and trachytes, pumice structure often preserved	Montmorillonite (Ca, Mg) $Al_2O_3.4SiO_2.nH_2O$	5 - 17%
	Water-laid breccia: Profile of weathering at top of breccia	Montmorillonite Index of refraction Beta less than 1.55	

FIG. 3. Generalized section of the clays at Castle Rock, Washington.

grains, it was formed after they were deposited as fragments by stream action (Fig. 2 b). The space around the clay pellets and grains provided openings along which ground water carried organic acids that leached silica and deposited gibbsite. About one third of the specimen photographed as Fig. 2 b is gibbsite and the clay contains about 42 per cent available alumina. Overlying the refractory clay at the Castle Rock open pit are clays high in iron that are composed of nontronite and beidellite with gibbsite developed around the edges of original sand grains (Fig. 2 c). This indicates that gibbsite can form from a clay low in alumina when open structures are present in the clay to permit diffusion of ground water solutions which remove silica and concentrate the alumina in the altered clay. Below the refractory clays at Castle Rock are clays low in available alumina composed of montmorillonite and re-

[5] Glover, Sheldon L.: Clays and shales of Washington. Dept. of Conservation and Development, Division of Geology, Bull. 24: 81–82, 1941.

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taining the structure of the volcanic glass from which they were derived. A typical specimen having only 5 per cent available alumina is shown as Fig. 2 d.

The clay deposits near Castle Rock [6] rest on a water-laid breccia. A profile of weathering at the top of the breccia required an interruption in sedimentation during which the breccia fragments at the top were weathered to montmorillonite (Fig. 3). On this profile of weathering sands, silts and clays were then deposited. Some of these were altered to montmorillonite and others to beidellite-nontronite which has higher available alumina than that of montmorillonite. In several areas beidellite-nontronite clays form a distinct zone between the underlying montmorillonite clay and the overlying kaolinite clays. The refractory kaolinite clays were probably formed from

In part from U. S. Bureau of Mines cores	GENERALIZED SECTION ROCK TYPES	CLAY MINERALS	Available alumina Courtesy of U. S. Bureau of Mines
	Quaternary terrace gravel and sand altered to clay which can be cut with a knife Lower part unaltered	Beidellite - Montronite $Al_2O_3.3SiO_2.nH_2O$ - $Fe_2O_3.3SiO_2.nH_2O$ Halloysite - Kaolinite - $Al_2O_3.2SiO_2.2H_2O$	20 - 28%
	Miocene stream deposits Clays - minor lignite; gravels and sands altered to clay Bentonites - volcanic glass altered to clay retaining shard textures Sediments suggest a mixing of materials from more than one source during deposition Some late alteration in situ Siderite at any depth Weathering zones; three recognized by R. L. Nichols in these clays	Kaolinite - Halloysite - $Al_2O_3.2SiO_2.2H_2O$ Beidellite - Montronite $Al_2O_3.3SiO_2.nH_2O$ - $Fe_2O_3.3SiO_2.nH_2O$ Gibbsite - $Al_2O_3.3H_2O$ from weathered feldspars and rock grains Minor celadonite $KAl\ Fe\ MgSi_3O_{10}(OH)_2$	18 - 32%

FIG. 4. Generalized section of the clays at Molalla, Oregon.

aluminous rocks outside of the Castle Rock area under conditions of thorough drainage and leaching and were deposited with a pellet structure in association with lignite. Locally, beidellite-nontronite or montmorillonite clays overlie the kaolinite clays. It is considered that the development of gibbsite took place in the interval following the deposition of the clays and before the extrusion of the basalt flows that now partially cover the clays.

MOLALLA CLAY DEPOSIT, CLACKAMAS COUNTY, OREGON.

The lower clays of the Molalla deposit, about 30 miles south of Portland, near Molalla, Oregon, have been described as altered tuffs.[7] Kaolinite in

[6] Allen, V. T., and Nichols, R. L.: Cowlitz high-alumina clay deposit near Castle Rock, Washington. Bull. G. S. A. 54: 1823, 1943.

[7] Wilson, H., and Treasher, R. C.: Preliminary report of some of the refractory clays of western Oregon. Ore. Dept. Geol. and Mineral Ind. Bull. 6: 43, 1938.

books and worm-like forms, beidellite-nontronite, small amounts of caladonite derived from volcanic rocks, and abundant diatoms in some types of clays indicate mixing of materials from several sources during sedimentary deposition (Fig. 4). During his study of this deposit for the Geological Survey, U. S. Department of the Interior, R. L. Nichols recognized three zones of weathering within the lower clays of the Molalla deposit. These were developed

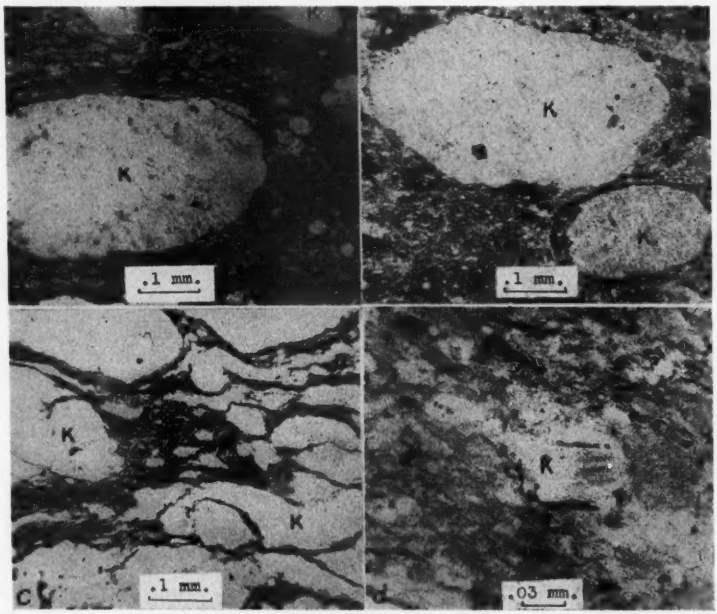

FIG. 5. a. Kaolinite pellets (K) surrounded by clay and organic material. Hobart Butte Quarry, Oregon.

b. Kaolinite pellets (K) surrounded by clay and organic material. Fulton, Missouri.

c. White kaolinite fragments (K) with high-iron clay and organic material filling cracks (C). Hobart Butte Quarry, Oregon.

d. Kaolinite book (K) in leaf shale. S. W. side of Hobart Butte, Oregon.

either by surface weathering during breaks in the sedimentary sequence or by ground water acting in the permeable parts. The writer has observed that kaolin minerals predominate in the clay types highest in available alumina but some gibbsite was formed from sand grains after their deposition. On the basis of fossil evidence the lower clays of the Molalla deposit are considered to be of Miocene age.[8] Apparently, fluvial conditions prevailed during the deposition of most of the sediments.

[8] Personal communication from John E. Allen.

Unconformably above the lower clay deposits is a second ore body which was formed by the weathering in place of Quaternary terrace gravels.

HOBART BUTTE CLAY DEPOSIT, LANE COUNTY, OREGON.

At Hobart Butte, Oregon, about 160 miles south of Portland, is a high-alumina clay that has been described as being composed of altered volcanic materials of andesitic composition belonging to the Calapooya formation of Eocene age. In the upper 200 feet of this deposit are kaolinite pellets (Figs. 5 a; 6) surrounded by organic matter similar to those in the flint clays of Missouri, Castle Rock, Washington, and other localities.[9] These structures have been referred to as "white bodies that look like altered feldspars," [10] but

FIG. 6. Sedimentary clay showing stratification, pellets and slickensides (S). Hobart Butte, Oregon.

actually are sedimentary accumulations of kaolinite clay that were plastic at the time of deposition, since some were molded against grains of quartz and rock fragments leaving one side free. Kaolinite is present as books in a leaf shale on the southwest side of the Butte 200 feet below the crest (Fig. 5 d). This is the characteristic habit of kaolinite in sedimentary rocks and suggests that a supply of kaolinite was available in the region for the formation of the pellets. In the Hobart Butte quarry are gray clays composed of white aligned fragments surrounded by clay containing organic matter and slightly more iron than that present in the white fragments. (No. 16 G, Table 2.) Some of the fragments fit together perfectly, indicating that large chips of kaolinite were deposited in water and as smaller parts split off, finely divided clay containing appreciable iron and organic matter was washed into the cracks (Fig. 5 c). The organic matter in the clay surrounding the pellets and breccia fragments (Table 2) is proof of deposition in water by sedimentary processes.

[9] Allen, V. T., and Nichols, R. L.: Clay-pellet conglomerates at Hobart Butte, Lane County, Oregon. Jour. Sed. Petrol. 15: 25–33, 1945.

[10] Wilson, H., and Treasher, R. C.: loc. cit.: 71, 1938.

Further proof is found in the charcoal, lignitic material, diatoms, and silicified wood in the pellet clays. The arrangement of the long axes of the pellets parallel to the bedding is evidence that the clays containing them are fluvial sediments. Some of these clays with sedimentary characteristics have an available alumina content of 33 to 35 per cent, which is the highest of any clays in the Hobart Butte district. The pellets and fragments in these sedimentary clays had the composition of kaolinite at the time of deposition. Fragments of a kaolinitic clay of the flint clay type are slightly plastic and do not disintegrate in water; thus they survive transportation and attain the features of these sediments. Kaolinitic clays which contain organic matter such as ball clays are plastic and, when wet, deform easily. Brown and gray fragments in the clays at Hobart Butte contain more organic matter than the white

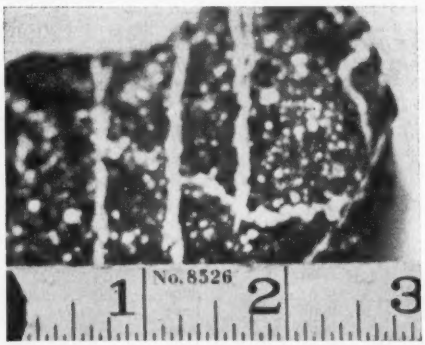

FIG. 7. Red iron stained clay containing white pellets and cut by white veins of dickite-kaolinite and quartz. Hobart Butte, Oregon.

fragments and many of these are squeezed and plastically deformed around the white fragments and pellets. Moreover, the X-ray and petrographic studies of the pellets, the breccia fragments and the matrix of the clays at Hobart Butte have failed to reveal remnants of another clay mineral from which the kaolinite could have formed. Fragments of pumice and welded tuffs, which are now white kaolinite and retain their original structures, are enclosed in a red, yellow or purple iron-stained matrix clay at various levels throughout the Hobart Butte area (No. 6, Table 1). The alteration of volcanic glass to kaolinite was completed at the time of deposition. If the alteration of the fragments to kaolinite took place after deposition, the red matrix would have been bleached by the solutions reaching the enclosed fragments. This is equally true of the white kaolinite clay pellets enclosed in a red or purple iron stained clay matrix (Fig. 7). Many features of the Hobart Butte high-alumina clays suggest their derivation from an Eocene profile of weathering which furnished not only white kaolinite clay for pellets and books but also red clay high in iron for the matrix material that surrounds white pellets and pumice fragments which had been previously altered to kaolinite.

TABLE 1.

ANALYSES OF CLAY TYPES AT HOBART BUTTE.

	1	3	5	6	7	10
Loss at 130° C.	0.44	0.23	0.64	3.97	0.16	0.17
Loss at 700° C.	10.15	9.71	10.50	8.26	5.95	8.80
Available Al_2O_3*	27.36	26.71	29.41	34.33	24.00	15.54
Available Fe_2O_3*	9.74	0.28	1.17	3.00	1.12	0.48
Available TiO_2*	0.14	<.02	<.02	.06	<.02	<.02

* Calculated on dry weight at 130° C., M. D. Foster, analyst.

1. Altered welded tuff, southwest side of Hobart Butte, near summit.
3. Kaolinite-quartz vein, lower part of Hobart Butte (fig. 11).
5. Water-laid breccia with yellow matrix, quarry at Hobart Butte.
6. White fragment from water-laid breccia with a purple matrix. Fragment is now kaolinite but retains relict texture of pumice. Quarry, Hobart Butte.
7. Altered tuff with relict shard texture, now kaolinite and quartz. W. M. Adams' property S 3, T 21 S, R 3 W, near Cottage Grove, Oregon (fig. 10).
10. Altered trachyte (?). Altered feldspars are now kaolinite and retain a flow arrangement. They have escaped the intensive silicification affecting the ground mass. Lower part of Hobart Butte.

TABLE 2.

CLAYS FROM THE QUARRY AT HOBART BUTTE.

	16G	16W	15	Q59
SiO_2	50.80	50.91		
Al_2O_3	33.45	33.67		
Fe_2O_3	.81	.50		
MgO	none	none		
CaO	none	none		
Na_2O	none	none		
K_2O	none	none		
H_2O − 110° C.	.61	.61		
H_2O + 110° C.	12.11	11.97		
TiO_2	1.92	1.99		
Organic Matter	.31	.16	1.31	2.80
	100.01	99.81		

W. W. Brannock, analyst.

16G. Water-laid breccia in which the long axes of white fragments are aligned in one direction and surrounded by dark gray clay containing organic matter and appreciable iron (Figs. 9, 5 c).

16W. Bleached zone—2 inches wide, at contact with 16G, and retaining the same arrangement of fragments in a white matrix (Fig. 9). Some organic matter and ferric oxide have been removed by hydrothermal solutions.

15. Organic matter of a clay-pellet conglomerate forming a 10 foot bed in which white pellets are surrounded by dark gray clay (Figs. 6, 5 a).

Q59. Organic matter in clay in which white pellets are surrounded by black carbonaceous clay.

Some of the clay at Hobart Butte was formed by the hydrothermal solutions that invaded the region, probably in late Miocene time, and deposited realgar, stibnite, pyrite, quartz, dickite-kaolinite at all depths (Fig. 8) as well as arsenates and other minerals. The distribution of sulphides along slickensided surfaces (Fig. 9) and in the matrix material of pellets and fragments

indicates not only that the sedimentary pellet clay antedates the slickensides but also that the slickensides served as one type of opening for the invading solutions. The hydrothermal solutions altered volcanic glass and lithic fragments to kaolinite. Some of the pumice retained its original texture during the alteration. One receives the impression that the cloudy isotropic to low birefringent material is the original glass, but all the specimens isolated and examined have the indices of refraction and the X-ray pattern of kaolinite. In many specimens the development of kaolinite from glass and lithic fragments was accompanied by the crystallization of quartz which is so fine-grained that it escapes detection except in X-ray patterns. However, in a few specimens quartz of microscopic size occurs as prismatic crystals with

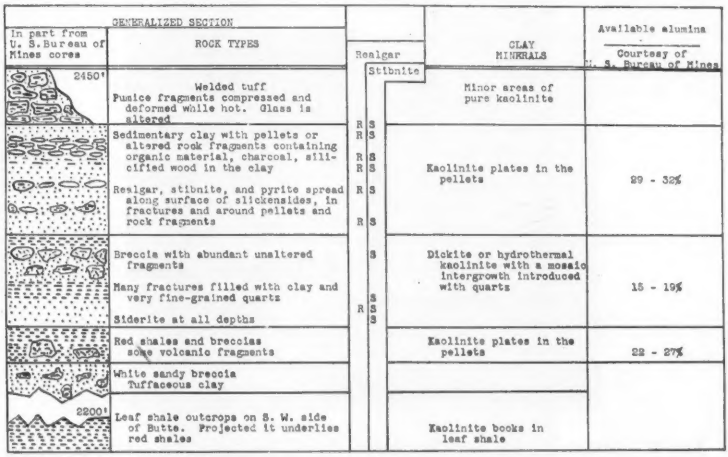
GENERALIZED SECTION
In part from U. S. Bureau of Mines cores
ROCK TYPES
Realgar
Stibnite
CLAY MINERALS
Available alumina
Courtesy of U. S. Bureau of Mines
2450'
Welded tuff
Pumice fragments compressed and deformed while hot. Glass is altered
Minor areas of pure kaolinite
Sedimentary clay with pellets or altered rock fragments containing organic material, charcoal, silicified wood in the clay
Realgar, stibnite, and pyrite spread along surface of slickensides, in fractures and around pellets and rock fragments
Kaolinite plates in the pellets
29 - 32%
Breccia with abundant unaltered fragments
Many fractures filled with clay and very fine-grained quartz
Siderite at all depths
Dickite or hydrothermal kaolinite with a mosaic intergrowth introduced with quartz
15 - 19%
Red shales and breccias some volcanic fragments
Kaolinite plates in the pellets
22 - 27%
White sandy breccia
Tuffaceous clay
2200'
Leaf shale outcrops on S. W. side of Butte. Projected it underlies red shales
Kaolinite books in leaf shale

FIG. 8. Generalized section of the clays at Hobart Butte, Oregon.

well developed terminations. At the summit of Hobart Butte, the glass of welded tuffs is altered to an isotropic material giving the X-ray pattern of kaolinite and quartz (No. 1, Table 1). A vitric tuff near Cottage Grove has been altered by hydrothermal solutions to submicroscopic quartz and a mosaic of kaolinite-dickite (No. 7, Table 1) so thoroughly that no distinction can be made under the crossed-nicols of a petrographic microscope between large shards and the fine material surrounding them (Fig. 10). The available alumina of these altered tuffs is 27.36 and 24.00 per cent and the available Fe_2O_3 is 9.74 and 1.12 per cent, respectively.

Clay of hydrothermal origin fills cracks ranging from 1 to 8 mm. wide at all levels in the Hobart Butte area (Figs. 7, 11). Such clay veins are more abundant at lower levels and all of those tested contain finely divided quartz. In thin section the white kaolin mineral in the veins shows the mosaic intergrowth characteristic of the massive dickite from Chihuahua, Mexico and

Neurode, Silesia. All the specimens from Hobart Butte, including one in which a few grains had an extinction angle of about 16° that is indicative of dickite rather than of kaolinite, gave the X-ray pattern of kaolinite. This suggests that the amount of dickite is too small to be recorded in the X-ray pattern of a mixture mainly kaolinite. The temperature of the hydrothermal solutions may have been sufficiently high at first to allow some dickite to crystallize but soon the temperature was lowered to a stage where kaolinite crystallized. The available alumina of a typical veinlet giving the X-ray pattern of kaolinite and quartz is 26.71 (No. 3, Table 1; Fig. 11) and like that of clays produced by hydrothermal solutions acting on tuffs is lower than the available alumina of typical sedimentary clays from the upper part of Hobart Butte.

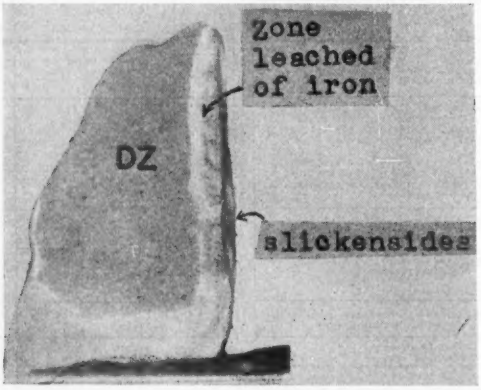

FIG. 9. A bleached zone in a block bounded by slickensides coated with realgar. Outer zone is leached of iron; dark zone (DZ) is composed of white kaolinite fragments surrounded by carbonaceous clay with appreciable iron. Hobart Butte Quarry, Oregon.

The possibility that the available alumina in the sedimentary clays was increased by the invasion of hydrothermal solutions has been considered during this investigation. The addition of veins of kaolinite and quartz to red and light colored clays decreased the available alumina of the invaded clay. A comparison of the 26.71 per cent available alumina of a typical kaolinite-quartz veinlet with the 33 per cent available alumina of the average sedimentary clay having a similar iron content at Hobart Butte demonstrates this beyond question. Bleaching of red clays to various shades of pink is noticeable in the lower levels at Hobart Butte. In the quarry gray clays are bleached white along slickensided surfaces that are coated with sulphides in a way suggesting that hydrothermal solutions caused the bleaching (Fig. 9). In a specimen of a gray water-laid breccia in which white elongate fragments are surrounded by a dark gray clay the unbleached portion was analyzed separately from the

bleached (16G and 16W, Table 2). The bleached zone is slightly lower in organic matter and ferric oxide than that of adjacent gray clay having the same structure, but its Al_2O_3 content is only .22 per cent higher and it contains no additional clay minerals. In fact the relative increase of alumina is of the order expected by the removal of the slight amount of organic matter and ferric oxide. In the laboratory, bleaching of the gray clay was accomplished by heating the specimen to drive off organic matter. After heating the original white breccia fragments remained white but the surrounding gray clay showed a fine network of red iron stained lines in a white bleached material. This indicates that the iron content of the gray carbonaceous clay is higher

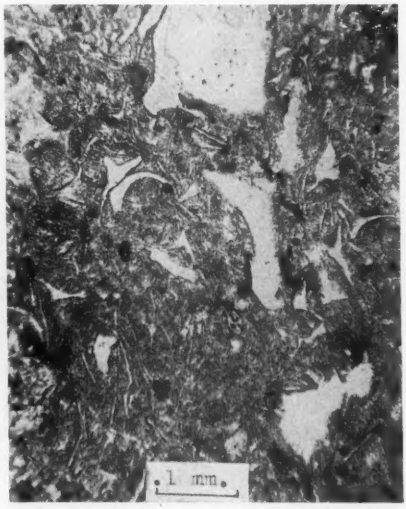

FIG. 10. An altered vitric tuff in which volcanic glass has been altered to a mosaic of kaolinite-dickite and fine quartz. W. M. Adams' property, near Cottage Grove, Oregon.

than that in the white breccia fragments. Bleaching of the gray portion was also artificially produced by boiling the specimen in concentrated hydrogen peroxide.

In attempting to evaluate the relative effects of the early weathering and sedimentary history as compared with those of the late hydrothermal stage it should be noted that the best grade clays at Hobart Butte are confined to the upper 200 feet of the deposit, where the features of the clays indicate a sedimentary origin (Fig. 8). The quality of the clay decreases with depth, which is opposite to what one would expect, if it were formed chiefly by hydrothermal solutions, since hydrothermal effects would tend to increase with depth, provided all other conditions remain constant. Throughout the deposit the com-

positions of the clays reflect the kinds of source materials that were being furnished during deposition. During the deposition of the upper sediments at Hobart Butte high-grade clay materials were contributed from a profile of weathering to the East. During the Eocene deposition of the low-grade clays many siliceous volcanic rocks that had either escaped alteration or had been silicified were deposited in the lower part of the section. In many samples the low alumina content may be correlated with the quantity of these unaltered rocks which retain characteristics acquired during their early volcanic history prior to deposition. In other samples low alumina is attributed to intensive silicification connected with the late hydrothermal activity of the Miocene. A pellet-bearing sediment forming the south pinnacle of Hobart Butte has the matrix but not the pellets silicified. The feldspars of some volcanic rocks are

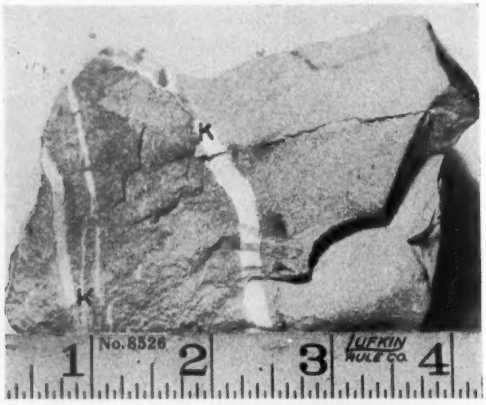

FIG. 11. Sedimentary clay cut by white veins of dickite-kaolinite and fine quartz (K), Hobart Butte, Oregon.

kaolinite that has escaped the silicification which converted the ground mass to quartz (No. 10, Table 1). Apparently the pellets and the kaolinized feldspars were less permeable than the matrix materials and were not replaced by the silica-bearing solutions. Also, the addition of siderite, pyrite and scorodite by hydrothermal processes increased the iron content of some clays at Hobart Butte and decreased proportionally their alumina content. Small siderite nodules are enclosed in dickite-kaolinite veins. Siderite and pyrite line the surfaces of dickite-kaolinite films that coat the fractures in the clay. This suggests an intimate relationship between these minerals and hydrothermal activity at Hobart Butte. Scorodite [11] has been observed to form in the hot springs of Yellowstone National Park, so that it as well as realgar and stibnite was contributed at Hobart Butte by hydrothermal solutions. At

[11] Hague, J. D.: Notes on the deposition of scorodite from arsenical waters in Yellowstone National Park. Am. Jour. Sci. (3) 34: 171–175, 1887.

many places in the Hobart Butte area hydrothermal activity was ineffective in producing a clay high in alumina and low in iron.

WHITEWARE CLAY DEPOSIT, FERGUS COUNTY, MONTANA.

At Whiteware, 8 miles northwest of Lewistown, Montana, is a dickite-kaolinite clay with a mosaic structure that was formed by the hydrothermal replacement of a fault breccia in which realgar, pyrite, and other hydrothermal minerals were introduced. Similar mineral assemblages at Whiteware and Hobart Butte indicate that the hydrothermal effects were about of the same intensity at these localities. The available alumina of the clay at Whiteware is higher than that in the best clay at Hobart Butte, but the total tonnage of hydrothermal clay at Whiteware is less than 1/70 of the entire upper ore body at Hobart Butte.

IRON MINERALS IN WESTERN CLAYS.

The iron minerals present in these clay deposits are of interest, because they are the source of the available iron that affects the cost of extraction of alumina from the clay. Four of the minerals listed in Table 3, siderite, hematite, limonite, and nontronite, account for most of the iron in the western clay deposits examined. Pyrite, ilmenite, vivianite, celadonite, and scorodite are locally important.

TABLE 3.

IRON MINERALS IN WESTERN CLAYS.

Siderite—$FeCO_3$	Hobart Butte, Oreg.; Castle Rock, Wash.; Molalla, Oreg.
Hematite—Fe_2O_3	Hobart Butte, Oreg.; Ione, Calif.
Limonite—$2Fe_2O_3 \cdot 3H_2O$	As stains at all deposits.
Nontronite—$Fe_2O_3 \cdot 3SiO_2 \cdot nH_2O$	Castle Rock, Wash.; Molalla, Oreg.
Pyrite—FeS_2	Hobart Butte, Oreg.; Whiteware, Mont.
Ilmenite—$FeTiO_3$	Mayger, Oreg.; Ione, Calif.
Vivianite—$3FeO \cdot P_2O_5 \cdot 8H_2O$	Castle Rock, Wash.
Celadonite—$(K)_{.84}(Al_{.34}Fe^{\cdot\cdot\cdot}_{.76}Fe^{\cdot\cdot}_{.24}Mg_{.76})Si_{3.89}Al_{.11}O_{10}(OH)_2$	Molalla, Oreg.
Scorodite—$Fe_2O_3 \cdot As_2O_5 \cdot 4H_2O$	Hobart Butte, Oreg.

Besides the aluminum-bearing scorodite recognized by Denning [12] at Hobart Butte, the pure aluminous end member has been found for the first time. For this mineral, the aluminum analogue of scorodite with a formula $Al_2O_3 \cdot As_2O_5 \cdot 4H_2O$, the name mansfieldite is given, in honor of George R. Mansfield, retired chief of the Section of Areal and Nonmetalliferous Geology, U. S. Geological Survey. The properties of mansfieldite will be discussed in another paper.[13]

[12] Denning, R. M.: Aluminum-bearing scorodite from Hobart Butte, Oregon. Am. Mineral. 28: 55–57, 1943.

[13] Allen, V. T., and Fahey, J. J.: Mansfieldite, a new aluminum arsenate, and the mansfieldite-scorodite series. Am. Mineral. In press.

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CONCLUSIONS.

The large deposits of high-alumina clays of the West, like those of the East, are dominantly of sedimentary origin. At Ione, Castle Rock, Molalla and Hobart Butte weathering and sedimentary processes have been effective in producing high-alumina clays. At Whiteware a small high-grade deposit has been formed by hydrothermal processes. At Hobart Butte some clay was formed by hydrothermal processes but the quantity is less and the quality poorer than that of the sedimentary clays. The formation of high-alumina clay at Hobart Butte has been attributed to three kinds of alteration, and the relative importance of each phase of alteration appears to be in the order in which it occurred there: (1) weathering and sedimentary deposition; (2) hydrothermal alteration; (3) alteration by meteoric waters.

At some deposits the structures acquired during sedimentation largely controlled the course of later solutions that increased the original alumina content of the clay.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
Dec. 5, 1945

STAGES AND EPOCHS OF MINERALIZATION IN THE SAN JUAN MOUNTAINS, COLORADO, AS SHOWN AT THE DUNMORE MINE, OURAY COUNTY, COLORADO.[1]

V. C. KELLEY AND CASWELL SILVER.

ABSTRACT.

The Dunmore lode is localized along a persistent fissure zone over two miles long and averaging nearly 100 feet in width along the length of the Dunmore claim. The fault in which the lode is located offset the pre-Cambrian quartzite and slate walls about 4,500 feet prior to deposition of the overlying thick San Juan tuff. Late Tertiary faulting extended the fissure into the San Juan tuff, dropping the south side about 80 feet. Although most of the lode crops out in the pre-Cambrian rocks, it extends upward across the profound unconformity into the tuff. The lode is complex, containing sharply marked fissure veins, sheared slate dragged into the fault zone, a sheared dike, breccia chimneys, and pebble dikes. An assemblage consisting of quartz, sericite, kaolin, and pyrite appears to be of early Tertiary age. The more productive part of the lode, however, is late Tertiary and consists of a hematite chimney inclosing a copper shoot, a tungsten chimney, and compound base-metal fissure veins. These chimneys and veins are mostly localized along early Tertiary structures, but their mineral sequences correlate them with the second stage of late Tertiary deposition recognized by Burbank in the adjoining Red Mountain and other districts. The Dunmore lode, however, is believed to have been deposited at greater depth and higher temperature and nearer to a source of supply than the lodes of these districts. In structure as well as mineral assemblages the Dunmore lode shows a connection between the chimneys and veins of the region.

INTRODUCTION.

THE mineral province in which the Dunmore mine is located lies in the San Juan Mountains of southwestern Colorado and includes the three mining centers of Ouray, Telluride, and Silverton.

The Dunmore lode is located on the west slopes of Red Mountain Creek about one quarter of a mile southwest of its junction with the Uncompahgre River and about four miles south of Ouray. The lower tunnel of the mine is at an altitude of 9,090 feet and is connected with U. S. Highway 550, on the east side of the canyon by a nearly horizontal tram 900 feet long.

The lode is an enlarged part of a persistent mineralized fissure zone over two miles long. The fissure zone strikes generally N. 73° W. in the vicinity of the lode, but its overall course is slightly concave to the north. The lode is nearly vertical in the vicinity of the Dunmore mine, but to the east on the Connie and Mountain Monarch claims it dips 70°–90° S.

The Dunmore lode is exposed for a distance of about 1,000 feet along the

[1] Published with permission of the Director, U. S. Geological Survey.

patented Dunmore claim. Throughout this distance it is about 100 feet wide, yet nowhere else throughout the two-mile course does the fissure vein approach so great a width.

Along the lode a steep-walled gulch has been eroded since the last or Wisconsin stage of glaciation. The difference in resistance to erosion between the several structural parts of the lode and the much harder wall rocks locally has given rise to very rough and irregular topography. The most conspicuous topographic feature of the gulch is the 200-foot north-wall cliff which exactly coincides with the sharp contact of the lode. Small pinnacles in the gulch consist of the more resistant rocks within the lode. Silver Creek closely follows the much sheared and weakened south contact of the lode, as can be seen in Fig. 2.

GEOLOGIC SETTING.

General Features.—The rocks of this part of the San Juan Mountains range in age from pre-Cambrian to Pleistocene, but in the immediate vicinity of the lode only two or three formations are present. (Fig. 1.) The oldest rocks of the area are the quartzites and slates of the pre-Cambrian Uncompahgre formation. To the north and northwest of the lode, near Ouray and in Canyon Creek, sedimentary rocks ranging in age from Devonian to Cretaceous crop out. These form a tilted wedge between the smooth westwardly sloping pre-Cambrian surface and the essentially horizontal middle Tertiary volcanic rocks.

The most prominent formation of the area is the thick Miocene (?) San Juan tuff. Andesite flows, breccias, and tuffs of the immediately overlying Silverton volcanic series (Miocene) are the most abundant other Tertiary rocks of the nearby area, but they have been eroded from the area shown in Fig. 1.

Thin lens-like layers of Telluride conglomerate (Oligocene?) only a few feet thick are found locally along the great unconformity between the Uncompahgre and San Juan formations. Sporadic patches of Wisconsin moraines and Quaternary talus cover the mountain slopes around the gulch, and great boulders 10 to 20 feet in diameter are lodged along the steep gulch bottom.

Pre-Cambrian Rocks.—The inclusion of a brief outline of Uncompahgre stratigraphy in this paper is necessary as a basis for the structural interpretation of the magnitude and direction of displacement along the Dunmore fault fissure, as different quartzites constitute the principal pre-Cambrian wall rocks of the lode.

The pre-Cambrian rocks of the immediate area belong to the Uncompahgre formation, which comprises alternating units of quartzite and slate (Fig. 1). They form a westwardly plunging anticline, whose axis nearly coincides in trend with the profound fault occupied by the Dunmore lode. Locally the quartzites are conglomeratic, becoming increasingly so in the lower part of the formation. Cross-bedded strata one to two feet thick are common throughout the quartzites. The horizontal component of displacement along the fault, 4,500 feet, is indicated by the offset of the quartzite unit of the Sutton Mill area (Fig. 1). This quartzite, which forms the south wall of the lode

at the Dunmore mine, is in marked contrast to the conglomeratic quartzite that forms most of the north wall. Slate beds 20–50 feet thick have been compressed into drag-folded zones which extend across the entire anticline. Locally the slates have been converted to mica, chlorite, or chiastolite phyllites.

The units or members of the Uncompahgre formation, shown in Fig. 1, aggregate about 7,000 feet in thickness. They are listed below, the oldest at the bottom.

UNCOMPAHGRE FORMATION IN THE VICINITY OF THE DUNMORE LODE.

No.		Feet
5.	Quartzites, white, sugary-grained, and evenly bedded	350
4.	Slates, black and greenish-black with common varve-like dark and light laminae. (Bear Creek locality)	750
3.	Quartzites, prominent, white beds at the top, brownish-red, argillaceous, and interbedded with slates toward the bottom. (Sutton Mill locality)	2900
2.	Slates, arenaceous with intercalated quartzite beds near the top and bottom; drag-folded zones near the bottom. (State Bridge locality)	1700
1.	Quartzites and conglomerates, gray to reddish-gray, conglomerate more common near the top and near the exposed lower beds. (Dunmore Mine locality)	1300

An additional thickness of about 1,700 feet of quartzite and slate lies above and north of this section in the area adjacent to Ouray. The base is not exposed, but the formation probably grades downward into the Vallecito conglomerate of the Needle Mountains group.[2]

San Juan Tuff.—The San Juan tuff is about 2,400 feet thick in the vicinity of the lode. Its generally thick and crude beds are nearly horizontal, but dips of 4°–8° WNW can be made out from favorable positions. The formation consists dominantly of gray, green, and purplish-brown volcanic fragments which range in composition from rhyolite to andesite. Beds of breccia are most common, followed by those of conglomerate and tuffaceous material. The formation on the whole represents a great alluvial fan washed from piles of flows and pyroclastic breccias to the east; yet, some mud flows, tuff accumulations, and occasional andesite flows may be found within the fanglomerate far from the volcanic centers. Intertonguing of the alluvial material of the San Juan tuff with many latitic and andesitic flows of the Silverton volcanic series can be seen near the east end of the Dunmore fissure zone along the east fork of the Uncompahgre River.

Dikes.—Dikes of two ages are found in the vicinity of the lode: those of pre-San Juan age and those of post-San Juan age. The older dikes were probably andesitic or diabasic, although their original composition has been much obscured by shearing and alteration. Two of them are found along the Dunmore fissure. On the Chrysolite claim adjoining the Dunmore on the east a highly chloritized dike about 50 feet thick occupies the south side of the fissure. A much sheared dike a few feet thick occurs along the north wall of the Dunmore lode; it has been considerably replaced by hematite. As a result of the intense shearing this rock has in many places a marked shaly structure. Its texture is fine-grained. Under the microscope it can be seen to consist almost entirely of the alteration products quartz, kaolin, sericite, and

[2] Cross, Whitman, Howe, Ernest, Irving, J. D. and Emmons, W. H.: U. S. Geol. Survey Atlas, Needle Mountains folio (No. 131), p. 3, 1905.

hematite. The original andesitic or diabasic composition of these two dikes is inferred from comparison with similar intrusives nearby whose original character has not been so thoroughly destroyed. No dikes of post-San Juan age are found along the lode, but they are present in the adjacent area. They consist of less altered andesites that are locally amygdaloidal and similar in

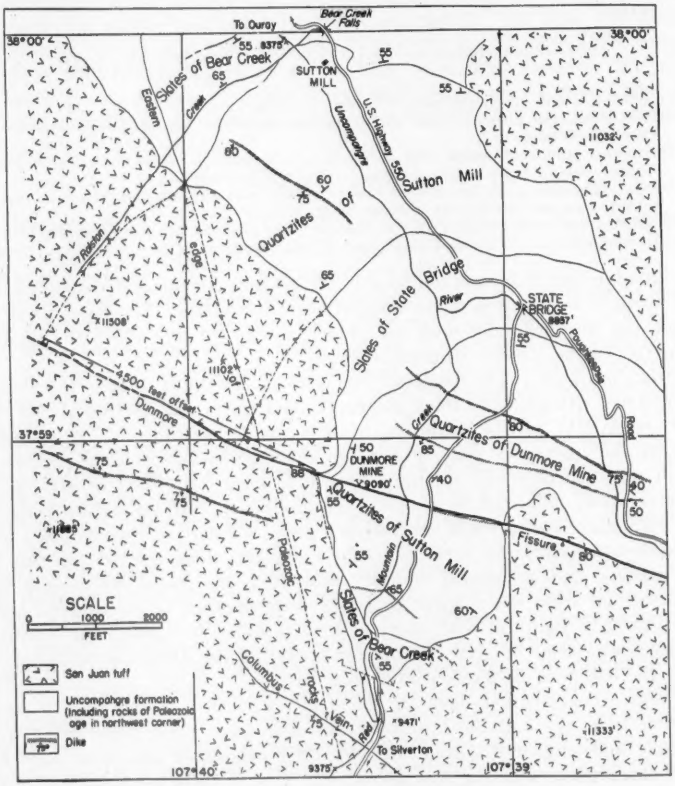


FIG. 1. Geologic map of the area surrounding the Dunmore mine.

appearance to the andesite flows of Hayden Mountain, about one mile southwest of the mine.

Structure.—The principal structural features in the vicinity of the lode are those of the pre-Cambrian rocks. The quartzites and slates of the Uncompahgre formation, as already stated, have been folded into a large westward-plunging anticline whose axial plane nearly coincides with the Dunmore lode. The pitch of the axis ranges from about 40° WNW on the east side of Red

Mountain Creek to 55° WNW on the west side near the lode. The dip on the limbs increases away from the axis, and amounts to 70° north of the area shown in Fig. 1.

A prominent set of fractures or joints lies roughly parallel to the axial plane of the fold. Those on either side of the axis diverge or fan out slightly in the direction of the pitch and dip toward the core of the fold. They appear to have been formed during folding by tension along the top of the anticline.

The Dunmore fissure was one of these tension joints which, with the culmination of folding, became a fault of considerable magnitude. The horizontal component of displacement along the Dunmore fissure prior to the deposition of the San Juan tuff is estimated to have been about 4,500 feet, the south side moving relatively east and/or down with respect to the north side. (Fig. 1.) The evidence supporting this interpretation is twofold: (1) the dragging of the beds adjacent to the fault and (2) the correlation of the slate and quarzite members of the Uncompahgre formation south of the fault with similar members north of the fault. The quartzites of the north wall of the lode are conglomeratic, of grayish color, and belong to those of the Dunmore Mine locality. Those of the south wall are white and resemble in lithologic character and stratigraphic position those of the Sutton Mill locality. Most of the displacement on the Dunmore fault probably occurred in pre-Cambrian time.

The San Juan tuff near the Dunmore lode is but little deformed. The only important products of deformation are the numerous, commonly persistent, coordinate sets of fissures and sheeted zones. There are sets of several trends in the general area, but those of most significance with reference to the lode strike N 10° W. They intersect the lode in great numbers near the exposed base of the San Juan tuff.

The Dunmore fissure was extended into the San Juan tuff in later Tertiary time prior to the principal late Tertiary mineralization, and displacements along it continued during and after the extensive ore deposition. The post-San Juan displacement dropped the south side 80 feet. (Fig. 2.)

GEOLOGY OF THE LODE.

General Description.

Along the principal part of the lode the strike of the walls is N 65° W. At the west end the strike changes to about N 75° W. and at the east end the strike of the north wall changes to about N 80° W. The dip of the lode is difficult to estimate. The prominent north wall along the central part of the lode is vertical. The south-wall break is poorly exposed at the surface, but even though the dips in the accessible parts of the underground workings are nearly vertical the disposition of the levels and the outcrop shows that, at least in the western part of the lode, the overall dip is steep to the south.

The lode comprises six principal structural elements: (1) well-marked north-wall, south-wall, and medial fissures, (2) dragged bands of slate, (3) dense, early, siliceous vein matter of the south half of the lode, (4) two ore

chimneys or pipes within the lode, (5) an unconformity within and adjacent to the lode, and (6) marginal veins and breccia dikes. (Fig. 2.)

The dominant structural features of the lode are the sharp regular breaks that mark its contact with the quartzite walls. These breaks are essentially parallel and about 100 feet apart along the middle section of the lode. Although they are of pre-mineral origin, they have also undergone post-mineral movements. The medial break forms the contact between the dragged-in wall-rock slates and the bulk of the vein matter that forms the south half of the lode.

Slates of the State Bridge locality, which overlie the quartzites in the north wall of the lode, have been dragged eastward into the fault across the sharply broken ends of the north-wall quartzites. There they form a band that occupies almost the northern half of the lode between the lower and upper tunnels. A few thin quartzite lenses are interbedded with the slates but are discontinuous because of the stretching and shearing that the dragged slate mass has undergone.

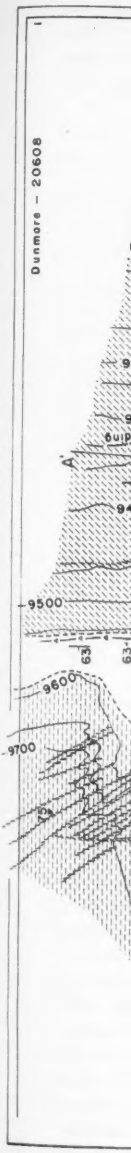
The slates in the lode are purplish-brown and possess a marked cleavage as the result of intense shearing in the fault. Under the microscope they are seen to be composed of much fine-grained angular quartz in a matrix of very fine-grained quartz, kaolin, and sericite. Fine-grained hematite and hematitic kaolin scattered along closely spaced shear planes are responsible for the purplish-brown color. Near the west end of the lode some slate of the Bear Creek unit has been dragged westward into the fault from the south wall, but this section is largely covered by the San Juan tuff.

The southern half of the lode is a dense mass of fine-grained vein matter. In some places it consists of chalcedonic quartz more or less impregnated with tiny pyrite crystals; in others sericite and kaolin are dominant and are more or less impregnated and replaced by fine-grained quartz.

Two breccia pipes lie within the vein matter of the lode. One of these is west of the upper tunnel portal and contains what is termed the hematite chimney; the other is about 150 feet east of the upper tunnel portal and contains the tungsten chimney.

The unconformity between the pre-Cambrian rocks and the San Juan tuff, intersected by the lode, is exposed above the upper tunnel in a big yellow-stained knob which stands up prominently in the gulch. This unconformity separates the wide part of the lode below it from the narrow part above. The unconformity slopes gently westward. (Fig. 3.) Because of the alteration associated with the hematite breccia chimney and copper ore shoot developed at this juncture of the lode, the unconformity at the base of the San Juan tuff is only distinguished with difficulty.

Pebble and breccia dikes occur locally along and in the walls of the lode. The smallest is only a few inches and the largest is about five feet wide. Those in the walls have been injected from the lode, as they pinch out within two hundred feet of it. Well-rounded pebbles of quartzite characterize most of these dikes, but the short, wide dike in the north wall consists of angular fragments entirely. Two of the bodies are in reality pebble sills formed along the bedding of the quartzite. The dikes near the slates generally con-



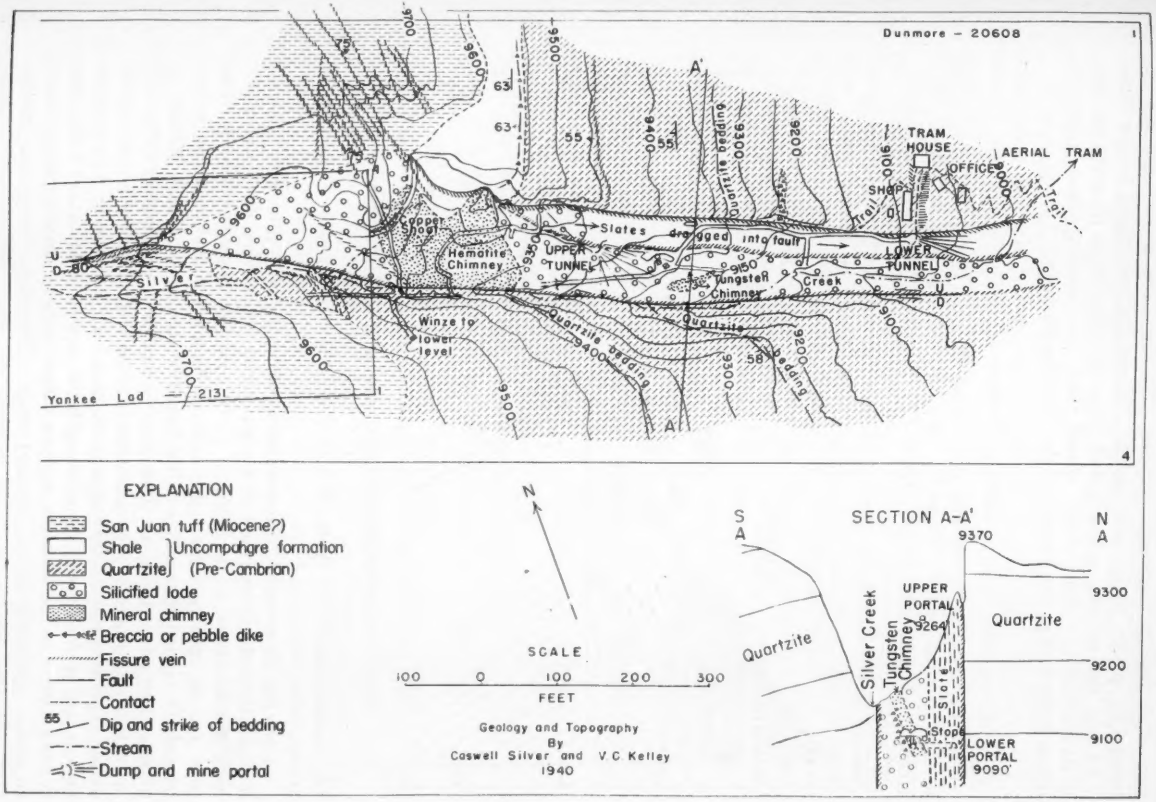


FIG. 2. Geologic and topographic map of the Dunmore lode.

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tain small angular fragments of slate. The fragments are mostly well cemented by quartz, pyrite, and kaolin. No ore has been found in the dikes. Two thin, rich-sulphide seams branch from the lode, one in its north and one in its south wall. Many closely spaced small veins striking about N 10° W. intersect the lode in the vicinity of the hematite chimney.

Mineral Deposits.

Six ore shoots within the lode and several marginal branch veins have been worked to some extent. These are grouped and described as follows: (1) Hematite chimney and copper shoot; (2) Tungsten (huebnerite) chimney;

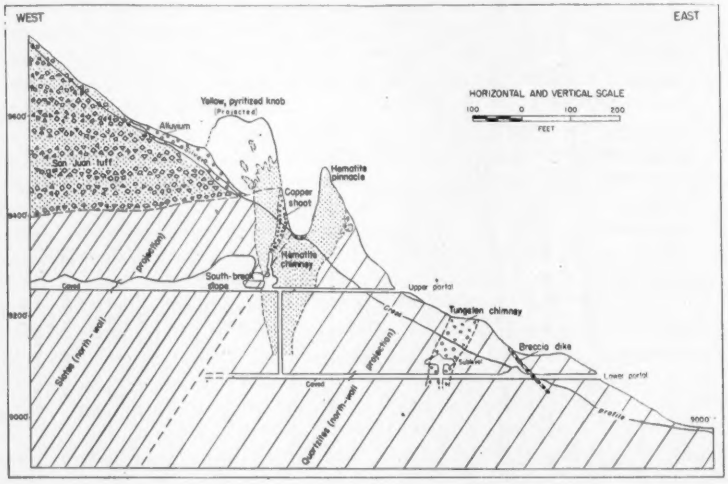

FIG. 3. Generalized longitudinal section of the Dunmore lode.

(3) South-wall vein; (4) North-wall vein; (5) Medial vein; (6) Marginal branch veins.

Hematite Chimney and Copper Shoot.—The hematite chimney in outcrop occupies the full width of the lode for about 180 feet between the hematite pinnacle and the yellow knob. (Fig. 3.) It is roughly the shape of an inverted cone with its apex near the south wall on the lower-tunnel level; its base is irregularly eroded in outcrop. The hematite chimney has been formed by more or less complete replacement of early quartzose vein matter (Fig. 4B) and slate. All stages in the replacement can be seen along the borders of the mass. The hematite chimney appears to have been localized by a steep channelway that approximately coincides with the copper shoot, where brecciation is most intense. The hematite replaces quartz, sericite, kaolin, and pyrite of an earlier (probably early Tertiary) stage. The early fine-grained assemblage was brecciated prior to the hematite deposition and there is evidence

that some further brecciation accompanied the formation of the hematite chimney. Thus, fragments consisting of early hematite and pyrite replacing a quartzose material are themselves replaced and cemented by later hematite and quartz.

In general, the hematite ranges from fine-grained, soft, greasy material to coarse platy aggregates of specularite about an inch in diameter. Pyrite is common and closely associated with the hematite in most places. Although most of the hematite clearly replaces the pyrite (Fig. 4A, B), it commonly occurs in densely banded finely granular colloform layers (Fig. 4C).

The copper shoot (Fig. 3) was developed later in the hematite chimney. It is roughly circular in cross-section, being about 25 feet in diameter near the surface but tapering downward. Its mineral assemblage consists of chalcopyrite, argentiferous aikinite, barite, rhodochrosite, and minor quantities of chlorite. At the margins of the copper shoot, both at the surface and underground, there are slabs of pyrite a few inches thick. Hematite was either reworked or continued to be deposited with the sulphides of the copper shoot. The gangue minerals of the copper shoot are distinctly later than the ore minerals. To summarize, the stages of mineralization represented in the hematite chimney and copper shoot are as follows:

(1) Fine-grained siliceous and pyritic vein matter (early Tertiary ?) largely equivalent to the first two stages in the tungsten chimney (see below).

(2) Pyrite, hematite, and quartz in which hematite replaces pyrite or is closely intergrown with pyrite and quartz.

(3) Hematite, chalcopyrite, and aikinite.

(4) Quartz, rhodochrosite, barite, and chlorite.

Tungsten Chimney.—The tungsten (huebnerite) chimney is in the southern half of the lode between the lower and upper tunnels. (Figs. 2 and 3.) At the surface the huebnerite shoot is about 15 feet wide and 50 feet long. The limits are not clearly defined, especially on the south and west sides, because exposures are so poor. In the outcrop a rather prominent sheeting is parallel to the dip of the body. Early fine-grained intergrowth of quartz, kaolin, and sericite are incorporated as fragments in later crystalline vuggy quartz. (Fig. 6A.) Huebnerite, pyrite, and a little sphalerite are closely associated with coarsely crystalline quartz. Marginal to the huebnerite shoot, and especially abundant in the hanging wall on the north side, is a grayish- to reddish-white quartz in which are imbedded pyrite euhedrons two to three millimeters in diameter. The pyrite, once nearly as abundant as the quartz in places, has been largely leached from the outcrop. Along its east end the huebnerite shoot contains a much-leached and delicate boxwork of laminated quartz. The boxwork appears to have been filled with pyritic and kaolinitic material which has been oxidized and washed out.

Underground the pipe-like form of the tungsten ore body is better developed. Much brecciation occurs in the tungsten-room sublevel about 20

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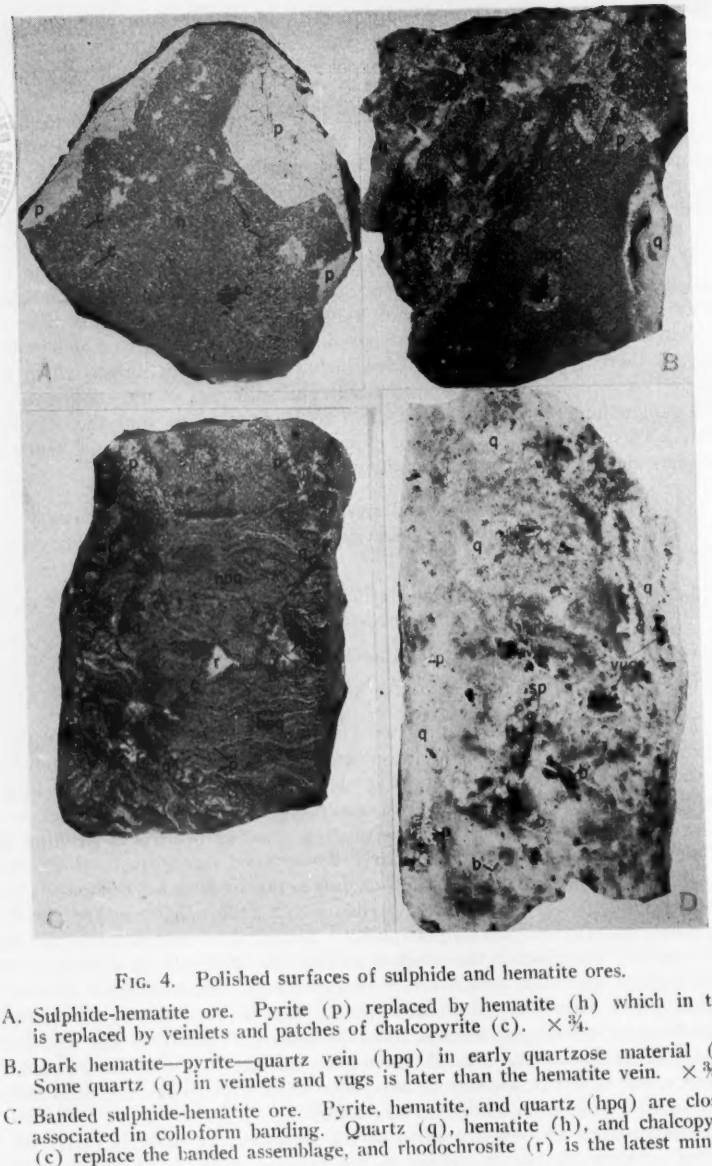

FIG. 4. Polished surfaces of sulphide and hematite ores.

A. Sulphide-hematite ore. Pyrite (p) replaced by hematite (h) which in turn is replaced by veinlets and patches of chalcopyrite (c). × ¾.

B. Dark hematite—pyrite—quartz vein (hpq) in early quartzose material (q). Some quartz (q) in veinlets and vugs is later than the hematite vein. × ¾.

C. Banded sulphide-hematite ore. Pyrite, hematite, and quartz (hpq) are closely associated in colloform banding. Quartz (q), hematite (h), and chalcopyrite (c) replace the banded assemblage, and rhodochrosite (r) is the latest mineral of all. × ¾.

feet above the lower tunnel. The structure and texture of this ore are well shown in polished surfaces. From these and thin sections of the quartzose vein matter the stages of mineralization were determined as follows:

(1) Fine-grained pinkish-white quartz having an average grain size of about 0.01 millimeter, but ranging roughly between 0.006 and 0.02 millimeter. (Fig. 5A, B.) Its rather opaque pink to white color appears to be caused by kaolinitic material which clouds the quartz. Sericite is sparingly and irregularly distributed in needles about 0.01 millimeter in length.

(2) Fine-grained translucent gray quartz of sutured and irregular grain, ranging from 0.02 to 0.05 millimeter. This quartz is clearer than that of (1) and contains less kaolinitic material generally. Sericite is more abundant, but is irregularly distributed in needles as much as 0.1 millimeter long. The quartzose material of this stage impregnates, replaces, and forms threadlike veins in the quartz of stage (1). (Figs. 6B, D.) Through the quartz of this stage are larger quartz grains about 0.3 millimeter in diameter. A few spots of radiating quartz and pyrite grains as much as 0.3 millimeter in diameter are also present.

(3) Medium- to coarse-grained translucent quartz with which huebnerite, pyrite, and sphalerite are associated. In this stage pyrite and quartz appear to represent the longest period of deposition. Barite is present in very minor quantities. Pyrite is early, forming granular crusts on the fragments of stages (1) and (2).

Tiny veinlets cutting the earlier quartzose material may consist of comb quartz along the walls and of quartz and huebnerite blades in the middle. (Figs. 5A, B.) The huebnerite crystals of these tiny veinlets range from about 0.05 to 0.5 millimeter in length.

In veinlets 0.1 to 1.0 inch in width, which fill in around the earlier fragments, there may be swarms of small fragments of the earlier quartz, which are usually crowded near the walls of the vein. (Fig. 6A.) In some of these veins a mushy mixture of quartzose material of the earlier stages and of fine-grained huebnerite of this stage appears to have been forced into the larger openings of the breccia. Vugginess is common in these veins.

Still larger openings as much as one foot in diameter in the breccia of stages (1) and (2) contain large stalactitic pendants of quartz, huebnerite, sphalerite, and pyrite. Huebnerite blades as much as an inch long are scattered or clustered in the quartz. The huebnerite may constitute 30 to 40 per cent of some of the masses. (Fig. 6C.) Pyrite is more abundant than sphalerite, but both are present in the pendants in only minor quantities. Quartz invariably forms a coarse-grained druse on the outside of the pendant forms.

The latest stage of mineralization is represented by kaolin, which veins the huebnerite (Fig. 6B) and forms a matrix to the stalactitic pendants. Whether

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D. Full-width section of one of the multiple veins that form the north-wall vein. Clouded patches in the quartz (q) consist of finely disseminated sulphides. Barite blades (b) are imbedded in quartz and extend into the vugs. Some pyrite (p) and occasional sphalerite grains (sp) are scattered through the quartz. × ¾.

this is supergene or hypogene koalin is uncertain, although fine pyrite crystals can be found in some of the material.

Intervals of fracturing and brecciation separated each of the above stages, but the principal brecciation came after stage two, when the breccia pipe was formed in which the huebnerite assemblage was later deposited. Even within stage three evidence of reopening can be found, later huebnerite-quartz veins cutting earlier ones.

South-wall Vein.—The gougy fissure vein of the south contact has been the most productive ore body of the lode. It is persistent and straight through-

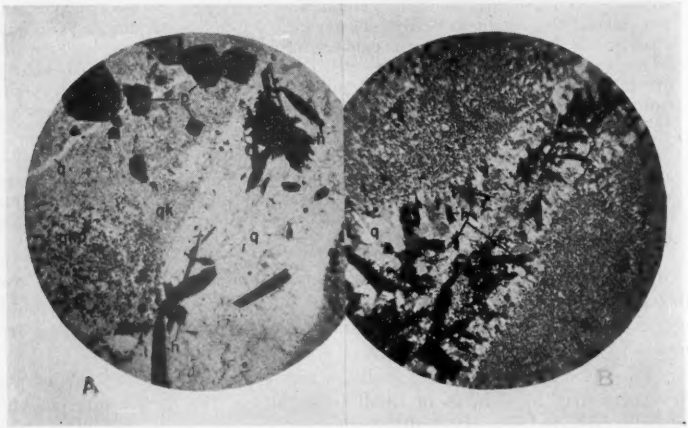

FIG. 5. Photomicrographs of altered slate, early quartz and huebnerite veinlets.

A. Veinlet of quartz (q) and huebnerite (h) in early-stage quartzose material. The very fine material (qk) is mostly quartz and kaolin; the intermediate-grained matrix (qkp) contains in addition sericite and pyrite. The large pyrite grains (p) belong to the tungsten stage. Plain light. × 35.

B. Veinlet of quartz (q) and huebnerite (h) in fine-grained aggregate of quartz, sericite, and kaolin. The plumose course quartz of the veinlet is clear whereas the late fine-grained quartz in the middle of the veinlet with the huebnerite is clouded. Crossed nicols. × 12.

out the length of the lode. It has been mined mostly on the upper level where at present the stopes are not accessible. Where observed in the drift leading to the main stopes it consists of slabby siliceous gouge, six to eight feet thick. It has been stoped for 20 to 30 feet above the upper level. It appears to have been a multiple siliceous and kaolinitic vein through which argentiferous galena and sphalerite were scattered. Some huebnerite has been found in the outcrops of this vein on the Yankee Lad claim west of the Dunmore. It is along this break that the fissuring was extended into the volcanic breccias in post-San Juan time. The vein has undergone considerable post-mineral shearing and brecciation which account for its present gougy and slabby character.

North-wall Vein.—The north-wall vein is narrow and rarely exceeds two feet in thickness where exposed. It terminates to the west where the slates enter the lode from the north wall. Altered and sheared slates form the south wall of the vein, and an andesite dike about one foot wide intervenes between the vein and the prominent north-wall quartzite. The vein consists dominantly of quartz with scattered galena, sphalerite, pyrite, chalcopyrite, barite, and rarely fluorite. (Fig. 4D.) Huebnerite is found in the vein near the lower tunnel and some hematite is incorporated in the vein where it passes the hematite body. The quartz is vuggy, and crystals of barite, sphalerite, and chalcopyrite occur in some of the vugs. Only minor post-mineral brecciation is present. The vein is very similar to the one in south-wall fissure.

Medial Vein.—The medial vein lies between the slates dragged from the north wall and the dense early siliceous matter of the south half of the lode. It is narrow and not a conspicuous feature of the lode. It consists of thin quartz stringers similar to the north- and south-wall veins. A little huebnerite occurs on it a short distance from the lower portal. The vein is cut on the lower level, and the entrance of the upper tunnel follows it for about 150 feet. West of and above the upper portal the medial vein is inclined to the south and the steep rise in the wall of the gulch nearly carries the vein to a junction with the north-wall vein. (Fig. 2.)

Marginal Branch Veins.—Several veinlets showing a mineral assemblage similar to that of the copper shoot occur as branches from the main lode. One of these, an inch thick, occupies a bedding plane in the quartzite that forms the north wall of the lode. It has been mined in a shallow inclined trench for a distance of 150 feet. It lies between two slaty quartzite beds and consists of tetrahedrite, chalcopyrite, and aikinite, with minor quantities of pyrite and barite but no quartz. Because of the cliffs forming the north wall, this vein could not be traced within less than 20 feet of the lode.

An almost identical seam occurs along the slate bedding in the south wall of the lode; it can be followed away from the lode for 60 feet. The average width of this vein is four inches. Intervening alluvium prevents the tracing of this vein into the lode. The ore of these veins is high in silver.

Paragenesis.—The Dunmore lode is the product of a long, varied, and complex mineralization. The earliest mineral assemblage appears to have been formed before the great volcanism of middle and late Tertiary time. It consisted of chalcedonic quartz, kaolin, sericite, and pyrite, but was largely barren of other sulphides and contained negligible quantities of gold and silver. It replaced slate and the crushed quartzite in fault breccia, and rather thoroughly filled voids in the breccia. The early mineralization was accompanied by brecciation which in part at least was so vigorous as to form breccia pipes in the lode and was under sufficient pressure to inject clastic dikes and sills into the walls.

The subsequent stages of mineral deposition took place after late Tertiary volcanism. They were located in both fissures and chimneys within the lode. As the deposits formed during the several stages are largely separate, the time relations between them are not directly disclosed; however, the sequence and

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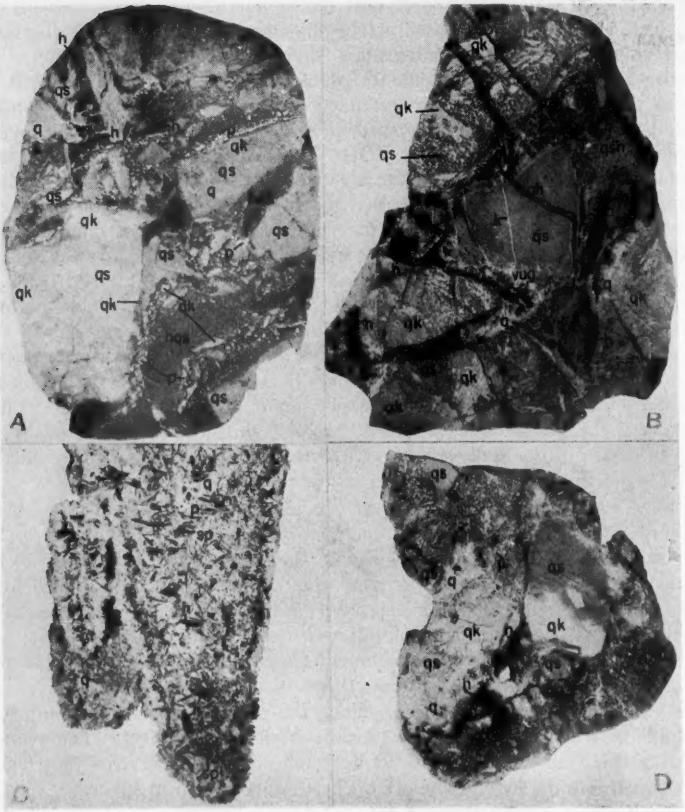

FIG. 6. Polished surfaces of tungsten ores.

A. Huebnerite breccia ore. Tungsten-stage minerals cement fragments of early-stage quartzose material in which milky translucent quartz and sericite (qs) cement and replace fragments of nearly opaque-white quartz and kaolin (qk). Small fragments of the early quartzose material are streamed with pyrite (p) in the huebnerite cement. Some of the huebnerite (h) is coarse and intergrown with quartz (hq); some is fine-grained and intergrown with quartz and sericite (hqs). × ¾.

B. Huebnerite breccia ore. Fragments of early stage quartz and kaolin (qk) and quartz and sericite (qs) cemented by quartz (q) and huebnerite (h). Some of the huebnerite cement is a fine-grained intergrowth (qsh) consisting of quartz, sericite, and huebnerite. The veinlet of kaolin (k) cutting the center fragment probably formed late in the tungsten stage. × ¾.

C. Stalactitic quartz (q) and huebnerite (h) in a pendant formed in a large opening in the tungsten breccia chimney. Quartz deposition outlasted that of

paragenesis within each of the bodies are determinable, as has been outlined above. The replacement of the early hematite assemblage by the copper minerals is clearly demonstrated. A small veinlet containing sphalerite and galena branches from the north-wall vein and cuts the copper shoot in the outcrop. This is the evidence for correlating the assemblages as shown in Fig. 7. The tungsten chimney contains some sphalerite and galena which were deposited before the huebnerite; furthermore, small quantities of huebnerite occur in the lead-zinc fissure veins, and here again its deposition is

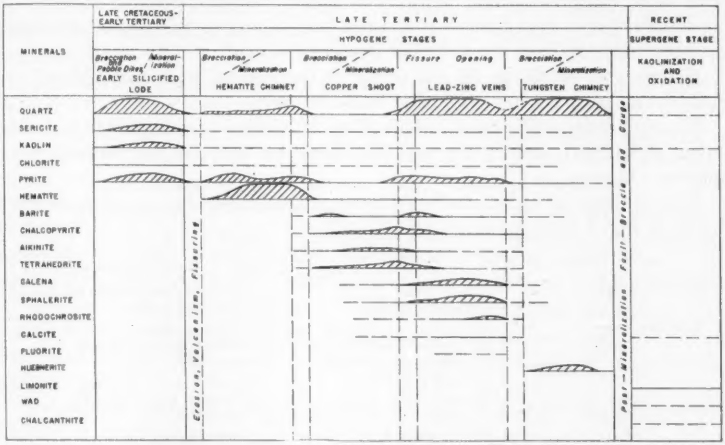

FIG. 7. Paragenesis chart of the mineral stages.

clearly late. Quite probably brecciation was either more often repeated or more continuous than diagrammatically shown in Fig. 7.

Contemporaneous though alternating deposition of hematite, pyrite, and quartz in the hematite chimney is demonstrated by the colloform banding of the three. (Fig. 4C.) Evidence for the post-hematite origin of the copper-shoot minerals is shown by the vertically cross-cutting position of the shoot in the hematite chimney, as shown in Fig. 3, and the numerous chalcopyrite-aikinite veinlets cutting the hematite. Some of the textural relations, however, suggest that hematite continued to be deposited at least in small quantity after the copper minerals began to form. Late veinlets of rhodochrosite contain some hematite.

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huebnerite to form a druse on the outside of the pendant. Some sphalerite (sp) and pyrite (p) are scattered through the pendant. × ½.

D. Huebnerite breccia ore. Sericitic quartz (qs) cuts kaolinitic quartz (qk) within early-stage fragments which are cemented by the tungsten assemblage consisting of huebnerite (h), quartz (q), and pyrite (p). × ¾. The relations between qs and qk are more clearly shown than in Fig. 6A.

Chalcopyrite, aikinite, and tetrahedrite appear to have formed at about the same time, but some textural evidence shows that deposition of the chalcopyrite outlasted that of the other two. Aikinite is found with chalcopyrite but never alone or with tetrahedrite. Where the three occur together in the marginal branch veins, aikinite forms blebs within chalcopyrite and is almost nowhere in contact with tetrahedrite. The marginal branch veins are not shown in Fig. 7 as a separate assemblage; they are considered to be contemporaneous with the copper shoot. Therefore, tetrahedrite, which is confined to the marginal branch veins, is included in Fig. 7 with the minerals of the copper shoot, even though it has not been found in the shoot. Enargite has been reported from the lode, but it was not found by the writers.

Galena and sphalerite do not occur in the copper-shoot assemblage, but chalcopyrite occurs sparingly in the lead-zinc veins.

Rhodochrosite and calcite, which form late veins and vug fillings in the copper shoot, also occur in the lead-zinc veins, but they are not present in the tungsten chimney.

The sequence of metals and associated gangue minerals (including pyrite) shown in Fig. 7 is summarized as follows:

	Metals	Gangue Minerals
Early Tertiary	iron (gold?, silver?)	pyrite, chalcedonic quartz, sericite, kaolin
Late Tertiary	(1) iron	pyrite, quartz
	(2) copper, bismuth, antimony, silver and gold?	rhodochrosite, barite, chlorite
	(3) zinc, lead, silver, gold	quartz, barite, pyrite, fluorite
	(4) tungsten	quartz, pyrite

ORIGIN AND SIGNIFICANCE.

The Dunmore lode reveals an unusually complete and varied sequence of ore deposition. Most of the deposition took place below the San Juan tuff, within which the lode becomes greatly narrowed both westward and upward. This abrupt change coming at the great unconformity between the pre-Cambrian and the Tertiary rocks is suggestive of two epochs of mineralization. Such a change, however, might be developed during a single epoch of mineral deposition by structural or physical differences in the fissure zone and the wall rocks, and these include (1) more periods of fracturing below the unconformity, (2) local strong quartzite walls, (3) damming effect along the fissure by relatively incompetent, inclined slate walls, (4) local change of strike, and (5) steepening of dip. That two epochs of mineralization actually took place, however, is indicated by the following facts:

(1) The mineralization below the unconformity is like that of the early Tertiary deposits to the north at Ouray, whereas the mineralization above the unconformity is characteristic of late Tertiary deposits.

(2) The existence of the strongly fractured zone in the pre-Cambrian rocks at the time of the nearby early Tertiary mineralization.

(3) The presence of breccia dikes and chimneys below the unconformity and their absence above it.

These points are further considered below.

The north and south walls along the lode on the Dunmore claim are dominantly of quartzite. These rocks are relatively strong and tend to maintain opened fractures. Slates form the north wall from a point near the upper portal westward for about 1,500 feet; about 350 feet west of the upper portal slates occupy the south wall westward for about 800 feet. Where both walls are slate the lode may be very greatly narrowed; beyond the slate walls to the west it may expand again within quartzite walls beneath the cover of San Juan tuff.

The slates of the walls west of the upper portal dip steeply west parallel to the pitch of the anticline. These slates, by maintaining a narrowed fissure, may have formed an inclined dam which could deflect the rising solutions to the east (Fig. 3) and could therefore constitute an important factor contributing to the greater width of the lode along the Dunmore claim.

Along the Dunmore claim the fissure has a somewhat more northwesterly strike than it has in the adjoining sections to the west and east. As described above, the principal displacement in pre-San Juan time was one in which the north side moved westward. Such a movement would tend to keep the more northwesterly trending stretches of the fissure closed; however, either a reversal of this displacement before deposition of the San Juan tuff or the post-San Juan displacement could have formed openings along the more northwesterly part of the fissure.

In the San Juan tuff the fissure dips 70°–90° S, and in the pre-Cambrian rocks it is nearly vertical. Since in post-San Juan time the south wall has dropped about 80 feet, the steeper pre-Cambrian part of the fissure could have been opened in this manner.

Finally, pre-San Juan weathering could have given rise to a more porous zone which extended down some distance below the base of the San Juan tuff, and later deposition might have been concentrated therein.

Burbank [3] in 1930 demonstrated that at Ouray there were two epochs of mineralization, one, late Cretaceous or early Eocene and the other late Tertiary; the former was dominant at Ouray, and Burbank [4] believed that mineralization related to the early Tertiary quartz monzonite stock at Ouray died out a few miles to the south. In this direction the late Tertiary mineralization becomes more prominent.

In view of the magnitude of the pre-Tertiary part of the Dunmore fissure zone, it is difficult to believe that it could have remained completely free from the mineralizing solutions of the early Tertiary. The Dunmore lode is only three miles east of the large early Tertiary quartz monzonite intrusive of Canyon Creek and 3½ miles south of the one at Ouray.

Although several breccia dikes and one breccia pipe are known in the pre-

[3] Burbank, W. S.: Revision of geologic structure and stratigraphy in the Ouray district of Colorado, and its bearing on ore deposition. Colorado Sci. Soc. Proc., vol. 12, No. 6, 1930.
[4] Oral communication.

Cambrian rocks near the lode, none is known in the volcanic rocks nearby, a fact suggesting if not proving the early Tertiary age of the breccia dikes in the Dunmore lode. The breccia dikes at Ouray have been shown to be genetically related to the early Tertiary mineralization.[5] It appears, therefore, that a part of the mineralization at the Dunmore lode may be early Tertiary. Since the fine-grained quartz, sericite, kaolin, and pyrite assemblage, the earliest in the lode sequence, does not occur above the base of the San Juan tuff, it may be a product of the early Tertiary deposition. Although it forms a considerable bulk of the lode, it was originally barren, and there is no doubt that the most important mineral deposition in the lode is of late Tertiary age. If the early, barren sequence is thus inferred to be of early Tertiary age, certain other conclusions may be drawn.

Oxidation or enrichment of the early Tertiary deposits was insignificant, since no such buried zone has been detected beneath late Tertiary primary ores in the San Juan tuff. The concentration of the early Tertiary assemblage in the quartzite can not be attributed with reason to the difference in steepness of the fissure zone across the unconformity as it can for the late Tertiary deposits. As pointed out above, the concentration of the late Tertiary deposits beneath the unconformity may have been influenced by more periods of fracturing. Obviously this factor had no effect upon the localization of the early Tertiary deposits. The other structural or physical factors enumerated on page 154 would be effective in concentration of lode matter during both epochs.

The history of the probable development of the Dunmore fissure and lode may be summarized as follows:

(1) Development of the fissure during deformation of the quartzites and slates of the Uncompahgre formation into a huge westward-plunging fold, probably in pre-Cambrian time.

(2) Displacement along the fissure resulting in about 4,500 feet of offset with accompanying brecciation, and the dragging of slates into the fault zone, probably in pre-Cambrian or early Paleozoic time; injection of diabasic dikes, profound erosion, and peneplanation.

(3) Probable extension of the fissure, by small normal displacements, into Paleozoic and Mesozoic sedimentary rocks.

(4) Barren mineralization in early Tertiary time from such intrusive centers as Ouray and Canyon Creek; development of breccia chimneys and pebble dikes; vigorous erosion exposing the early lode in low to moderate relief, mostly in pre-Cambrian terrain. The more resistant south side of the lode stood in relief above the north side along the Dunmore claim at this time.

(5) Burial of the lode by several thousand feet of San Juan tuff and the Silverton volcanic series.

(6) Extension of the fault into the volcanic rocks, the south side dropping about 80 feet.

(7) Passage through the lode of vigorous late Tertiary, ore-forming solutions which spread above the pre-Cambrian rocks into the volcanic rocks along numerous fissures that branched both upward and outward from the trunk channel. During this last stage, which was long and complex, the ore bodies within the pre-Cambrian part of the lode were deposited.

[5] Burbank: op. cit., p. 214.

Burbank,[6] following Purington,[7] has pointed out that the late Tertiary veins in the San Juan area are compound as the result of three major stages of mineral deposition. The first major stage is best developed in the Telluride-Sneffels area to the south of the Dunmore lode near the Red Mountain caldera center in what Burbank [8] has termed the inner zone. It consists of lead-zinc-copper deposits in quartz gangue. It is best displayed in such mines as the Barstow and Mountain King along the west side of Red Mountain Valley. This stage diminishes in prominence outward or to the northwest in Burbank's intermediate zone where the second stage is dominant. The veins of this stage are characterized by quartz with minor quantities of chalcopyrite and other base-metal sulphides.[9] Specularite and rhodochrosite are also found in this stage in the intermediate zone and gold-bearing quartz is included here as a sub-stage. This stage of veins is prominent in such mines as the Camp Bird, Smuggler, and Tomboy. The third stage is mostly in an outer zone at such mines as the Liberty Bell and Smuggler Union and consists of barren or low-grade quartz with some pyrite. In the intermediate zone fluorite may be locally abundant.

In the Dunmore lode the late Tertiary deposits are to a considerable extent localized on structures that originated during the early Tertiary. In Fig. 7 four late Tertiary stages are shown to be represented in the Dunmore lode. The copper-shoot assemblage might be considered the product of a substage that followed the hematite stage. The marginal branch veins containing tetrahedrite and aikinite are probably also best included in this stage. On the basis of the presence of rhodochrosite, hematite, and tetrahedrite, the assemblage might be best correlated with Burbank's second stage. If so, the lead-zinc veins of Burbank's early stage (inner zone) are not represented in the Dunmore lode; instead, a lead-zinc stage followed the hematite-chalcopyrite stage at the Dunmore. It should be pointed out that the lead-zinc tenor of the Dunmore assemblage is not nearly as high as that commonly present in the inner-zone deposits described by Burbank. Probably the Dunmore quartz-lead-zinc veins are correlated best as a stage or sub-stage between Burbank's stages two and three.

Too much dependence can be put upon an assumed order of mineral deposition when applied to disconnected deposits, especially if they are widely separated. In all probability the base-metal sulphides may be both early and late, and abundant or uncommon in different deposits. Other factors that may have been important during deposition of the Dunmore lode are (1) depth and temperature, (2) nearness to a local supply of ore-forming solutions, and (3) structure of the local channel-way. The temperature is difficult to evaluate, but it is evident that the pressure by reason of depth was relatively great at the Dunmore lode. It has been estimated that the late Tertiary mineraliza-

[6] Burbank, W. S.: Structural control of ore deposition in the Uncompahgre district, Ouray County, Colo. U. S. Geol. Survey Bull. 906–E, p. 248, 1940.

[7] Purington, C. W.: Preliminary report on the mining industry of the Telluride quadrangle, Colo. U. S. Geol. Survey, 18th Annual Report, pt. 3, p. 799, 1898.

[8] Op. cit., p. 250.

[9] Burbank: op. cit., p. 251.

tion took place at a depth of nearly 6,000 feet.[10] This factor alone may be responsible for the abundance of hematite. The Dunmore fissure is marginal rather than radial with reference to the late Tertiary centers in the Red Mountain district. The prominence and deep-seated origin of the fissure have been described, and it may well be that in late Tertiary time the fissure tapped and was fed by ore-forming solutions from a separate source than those at Red Mountain. If so, the sequence of mineralizing solutions and hence stages of deposition might not necessarily be quite identical with those in the area to the south.

In many deposits of the San Juan region local structures appear to have controlled the type of mineralization. For example, enargite is essentially confined to chimney deposits or breccia pipes. Until recently chimney deposits of enargite had been thought to be confined to the Red Mountain district, but in 1945 [11] an identical enargite assemblage was found in lower Poughkeepsie Gulch, some four miles from the Red Mountain district. The enargite of this occurrence was in a breccia dike. Enargite has been reported from the Dunmore by the owners, but the writers have seen none and do not know the position in the lode from which it was supposed to have come. It most likely would have occurred in the copper shoot of the hematite chimney. It therefore appears that in the San Juan region enargite is related to conditions that prevailed during the development of breccia chimneys and dikes.

The structure and texture of the Dunmore chimneys are not wholly unlike those of the Red Mountain chimneys. Perhaps the breccia chimneys and dikes at the Dunmore indicate action similar to that in the Red Mountain district, but deeper seated. The fissure along the lode appears to have been a deep feeder or trunk channel to shallower surrounding fissure veins. The Dunmore lode may be conceived as a fissure deposit within which are located pipe or chimney deposits. As such it has affinities to both the fissure and chimney deposits. In structure as well as mineral assemblages, it shows a connection between the two types of deposits.

The copper shoot and its assemblage, although showing mineralogically some of the aspects of fissure deposits in the intermediate zone, may be related on the basis of structure and texture to the chimney deposits of Red Mountain. The copper shoot may, therefore, be equivalent to the enargite assemblage of Red Mountain. At the Dunmore lode the copper mineralization was superimposed on that of the older hematite chimney in a "telescoped" relation.

The deposits at the Saratoga mine two miles south of the Dunmore and about three miles north of the principal Red Mountain deposits contain some hematite. The Saratoga deposits are intermediate in altitude between the Dunmore lode and the Red Mountain deposits and may be fed from pipes that are not exposed. The lowest levels of the Camp Bird veins contain much hematite. Perhaps hematite can be expected at depth in the Red Mountain deposits.

[10] Kelley, V. C.: Geology, ore deposits, and mines of the Mineral Point, Poughkeepsie, and Upper Uncompahgre districts, Ouray, San Juan, and Hinsdale Counties, Colo. Colorado Sci. Soc. Proc., vol. 14, No. 7, p. 330, 1945.

[11] Idem, pp. 398–399.

The huebnerite veins contain the latest important assemblage of minerals wherever they are present in the San Juan region. Huebnerite is found through a considerable vertical range from more than 11,000 feet to less than 9,000 feet in altitude. It is not present in the early Tertiary deposits and is generally most common either in the Silverton caldera surrounding the Red Mountain district or in the inner zone of radial fissure veins not far outside of the caldera. The Dunmore fissure vein lies at a considerable distance from the caldera margin. The explanation again may lie in the deep-seated penetration of the fissure, which was able to tap solutions otherwise only rising in or near the caldera.

The field work leading to this paper was done primarily under the auspices of the U. S. Geological Survey in cooperation with the State of Colorado and the Colorado Metal Mining Fund during the summer of 1940. The compilation of the paper and the laboratory work was done in the Department of Geology, University of New Mexico. Acknowledgment is gratefully tendered to G. F. Loughlin, W. S. Burbank, and Carle H. Dane, all of whom read and criticized the manuscript.

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STRUCTURAL CONTROL OF ORE BODIES IN THE JEFFERSON CITY AREA, TENNESSEE.*

ARNOLD L. BROKAW AND CHARLES L. JONES.

ABSTRACT.

The zinc deposits of the Jefferson City area are confined to the lower half of the Kingsport formation of the Knox group of rocks. They are on the southeast flank of a northeast-trending anticline which is partially overridden from the southeast by the Bays Mt. thrust sheet. The beds show low dips. The area is transected by a series of high angle strike-slip faults having relatively small displacement and striking essentially parallel to the dominant northeast structure. Minor cross folds running transversely to the regional structure are numerous. Three sets of fractures trending N. 45–50° W., N. 30–40° E., and N. 60–70° E. are well developed.

The ore bodies are irregular but generally have a distinct elongation. The vertical extent may be limited to a single bed or may include several beds, depending upon local structural conditions. All ore bodies are confined to zones of pre-mineral deformation. The linear trends of the ore bodies show a remarkable parallelism to the axes of the cross folds. Ore occurs on any part of the flexures but maximum concentration is on the anticlinal crests and synclinal troughs; the ore attains greatest thickness on the anticlines. Fractures associated with the folding exhibit local ore control. Faults are poor sites for ore, but fracturing and drag folding accompanying faulting produce conditions favorable to ore deposition.

INTRODUCTION.

DURING recent months members of the Geological Survey have been engaged in detailed areal and underground mapping in the East Tennessee zinc district. One objective has been to determine the geologic factors controlling the individual ore shoots within an ore body. Although the investigations are not complete, some factors can be recognized with confidence. It is the purpose of this paper to discuss briefly, with a minimum of detailed examples, the relationship between minor folds and the trend of ore shoots. Later a detailed report is to be published which will describe this relationship fully and will cite numerous examples.

Heretofore emphasis has been placed upon faulting, fracturing, and favorable beds as factors controlling the distribution and lineation of the ore bodies in the Jefferson City district.[1] Such structural and stratigraphic features are recognized as important parts of the geologic control, but fracturing is the

* Published by permission of the Director, U. S. Geological Survey.

[1] Crawford, Johnson A.: Structural and stratigraphic control of zinc deposits in east Tennessee. (Abstr.) ECON. GEOL., vol. 40, p. 81, 1945. Currier, L. W.: Structural relations of southern Appalachian zinc deposits. ECON. GEOL., vol. 30, pp. 260–286, 1935. Newman, Mark H.: Zinc ores of east Tennessee. Eng. and Min. Jour., vol. 139, No. 8, pp. 43–44, 1938.

only one of these that has more than secondary importance in determining trends of mineralized zones. The presence of anticlinal, synclinal, and monoclinal flexures with accompanying brecciation and fracturing in and near ore bodies apparently has been more influential in determining the direction of a particular shoot than has been previously recognized.

GENERAL STRATIGRAPHY.

All the ore bearing beds of the Jefferson City area are confined to the lower two thirds of the Kingsport formation of lower Ordovician age. Oder and Miller,[2] on the basis of lithology, divide the formation into four major units, as follows: "The upper division is composed of 101–135 ft. of fairly light to dark fine-grained dolomite, with a little interbedded brown limestone. Arenaceous beds and dark nodular cherts are numerous. The underlying 44–50 ft. consists of light brownish gray to nearly white, extremely fine-grained dolomite, some of which is nearly lithographic in texture. Gray concentrically banded chert nodules are characteristic. The light colored division just described is underlain by a variable zone 33–38 feet thick. It is made up of light to dark gray to brownish fine-grained to finely crystalline dolomite and some brown limestone, which may be altered to crystalline dolomite. The lower 178–216 ft. of the formation forms the fourth division. It consists mainly of brown limestone, which in many places is altered to crystalline dolomite. Interbedded with the limestone is some light to dark gray fine-grained dolomite. Cherty layers, especially of the irregular and banded type, are numerous." All of the major units have been further subdivided into more detailed and more useful division.[3]

STRUCTURE.

The ore bodies are on the southeastern flank of a northeast-trending anticline which has been partially overridden by a major thrust sheet from the southeast. The dip of the beds is generally at a low angle, but locally shows some steepening. The area is transected by a system of northeast trending high angle faults having small vertical and large horizontal displacement. Generally, the strike of these faults and the strike of the thrust fault converge to make an acute angle. Considering the geometric relationship of the faults and the type of displacement, they can be best classified as strike-slip faults. It is believed that they were formed during the epoch of thrusting. Local departures from the regional structural pattern present evidence that strong rotational stresses have been active. This accounts for some of the incongruities between the trends of folds and variability in the strikes of the faults as well as for the displacements on the strike-slip faults transverse to the regional stresses. Some bedding plane faults and minor thrusts are present.

Minor cross folds have been formed on the major anticline. In general, their axial trend is east to northeast, but in some areas this changes to a

[2] Oder, Charles R. L., and Miller, Howard W.: Stratigraphy of the Mascot-Jefferson City zinc district. Am. Inst. of Min. and Met. Eng., Tech. Pub. No. 1818, 1945.

[3] Idem, pp. 6–8.

southeast direction. These folds cause only minor displacement of the beds. Contouring on key horizons reveals no folds on which there is closure but rather a series of alternating anticlinal and synclinal noses that die out in relatively short distances. In some instances, a crude *en echelon* pattern is developed.

Three sets of fractures have trends of N. 45–50° W., N. 30–40° E., and N. 60–70° E. The N. 30° E. system is most pronounced.

ORE BODIES AND STRUCTURAL RELATIONSHIP.

The mineralogy of the ores is comparatively simple. The ore mineral is sphalerite associated with a large amount of hydrothermal dolomite and a small amount of calcite and pyrite. The ore occurs as replacement deposits in coarsely crystalline dolomitized limestone, in unaltered limestone, and as filling and cementing material in fine grained dolomite breccia. In such breccias there is little evidence that the sphalerite has replaced the dolomite fragments.

In outline, the ore bodies are more or less irregular, but they generally show a distinct elongation. The vertical extent may be limited to a single bed or may include several beds depending upon local structural conditions. All ore bodies and individual shoots are confined to zones of premineral deformation. This deformation, causing only slight flexing of the beds, resulted in minor anticlines, synclines, and monoclines. Many of the folds are hardly perceptible and are revealed only by careful mapping and contouring on key beds.

The linear trend of the ore shoots shows a remarkable parallelism with the axes of the flexures (Figs. 1, 2). The ore may occur on any part of the structure, but generally the maximum concentration is on or near the crest or trough. In areas where the folds are closely spaced, a series of shoots may be mined as a single stope. In such stopes, the outline of the stoped area is very likely to give an erroneous picture of the true relationship to structure. Ore deposited on anticlines has a greater thickness than that deposited in the synclines. This is probably best explained by the generally accepted assumption that the easiest relief from the stresses involved in the deformation was upwards and away from the source; if the rocks yield to stresses more easily in this direction, it follows that maximum fracturing and brecciation would occur on the resulting anticlines. When the limits of the deformed area are approached, the intensity of the brecciation and fracturing declines, and the concentration of ore decreases in consequence.

In brief, any flexing of the beds will produce optimum conditions for ore deposition. The simple monocline or "roll" having only a few feet displacement will be a favorable site for an ore shoot with the long axis parallel to that of the fold. Similarly, small anticlines and synclines are favorable structures (Figs. 1, 2).

Fractures, probably associated with the flexing, also exhibit local control of ore deposition. Ore may be highly concentrated along a fracture or set of fractures, but in a short distance this same system may have acted only as a conduit for the ore solutions in transit to more favorable zones for deposition.

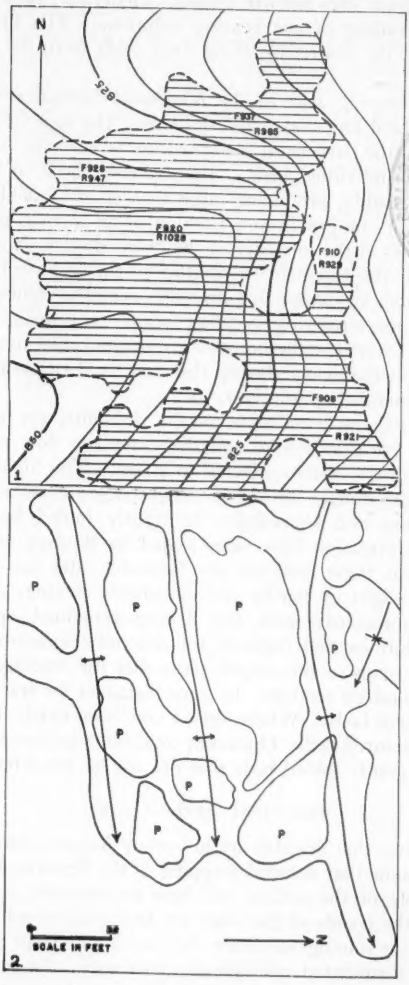

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FIG. 1. (Upper) Structure map showing the relation of structure contours to a stoped area (shaded), Jarnagin mine, Jefferson City, Tennessee. Structure contours are on a key horizon in Lower Kinksport formation. Figures designate elevations in feet; "F" for floor and "R" for roof.

FIG. 2. (Lower) The relation of fold axes to a stoped area, Davis mine, Jefferson City, Tennessee. P represents pillars and lines with arrows are anticlinal axes.

Faults alone are poor sites for ore shoots. Generally, they are too tight to permit lateral spreading of ore bearing solutions. The brecciation accompanying faults and the shattering along drag folds form the loci of good ore bodies.

Since the ore bearing zone of the Kingsport formation consists of a sequence of interbedded limestones and dolomites, the type of fracturing in the rocks involved in the structural deformation is directly controlled by the competency of the individual beds. The dolomite beds in the ore zone are brittle and break readily, producing large masses of "crackle" breccia. The size of the fragments ranges from a fraction of an inch to several feet in diameter. Regardless of the intensity of the brecciation, it is evident that there has been very little displacement or rotation of the fragments. It is believed that most of the breccia, except that directly related to faulting, resulted from folding and the accompanying bedding plane movements. The size and grade of ore bodies found in the breccias are proportional to the volume of the openings formed mechanically during the structural deformation, and to the richness of the mineralizing solutions.

In contrast with the brecciation of the dolomite, the limestones in the Kingsport, which are thin-bedded and shaly, tend to flow much in the manner of plastic materials when subjected to stress. The highly contorted, discontinuous, and abnormally thickened shale zones present are believed to be evidence of flowing and squeezing. In tightly folded beds, the openings formed during deformation have been sealed by flowage of shale and limestone beds. Hence, these folds are not favorable sites for ore accumulation. In areas of only slight or hardly distinguishable flexing, the fractures that formed contemporaneously with the flexing remained open, allowing an ingress of ore solutions that replaced the dolomitic limestone. It is evident from the detailed maps of the stoped areas that the fractures are more common within the limestone section. In some instances the fractures are not continuous into adjacent beds. Where such a condition exists, the ore bodies are confined to the fractured bed. Optimum conditions for ore bodies in the limestone section are gently folded beds that are cut by persistent fractures.

PRACTICAL APPLICATIONS.

Since it is known that flexures are important factors controlling ore shoots, it is logical to assume that detailed mapping of the flexures, both underground and, where possible, on the surface, will have an economic value in mining and prospecting. If the trends of the folds are first established within a mineralized zone, plans for mining to obtain the maximum yield with the least expenditure can be formulated with greater assurance. In surface prospecting, the recognition of flexures beforehand would mean the possible elimination of many "dead holes." Areal mapping in this district by other members of the Geological Survey has shown that the small flexures can be mapped and that they show a definite relationship to known zinc and barite deposits.[4]

[4] Kent, Deane F., and Rodgers, John: Zinc deposits of the Copper Ridge, Straight Creek, and Powell River areas of east Tennessee. (Abstr.) ECON. GEOL., vol. 40, p. 88, 1945. Dunlap, John C.: Structural control in the eastern belt of the Sweetwater barite district, east Tennessee. (Abstr.) ECON. GEOL., vol. 40, p. 82, 1945.

ACKNOWLEDGMENTS.

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NOTES ON THE CUTTING AND POLISHING OF THIN SECTIONS.

CHARLES MEYER.

ABSTRACT.

Soft clay-bearing and otherwise friable rocks that cannot be shaped or mounted without preliminary treatment are impregnated with lucite monomer. Polymerization of this agent is accomplished overnight by accelerated heating and use of a sand filler around the specimen. After this impregnation even montmorillonite-rich samples need be shown no additional special attention throughout the remainder of the routine of sectioning.

All sections are mounted with Lakeside No. 70 thermoplastic cement. Then, instead of grinding away the excess rock with coarse abrasives, thin sections are cut rapidly and evenly to about 0.08 mm. or less on a specially built diamond saw. Finishing down to 0.03 mm. may then be accomplished by hand on a power lap or glass plate, for covering in the usual manner, or the sawed sections may be placed in adjustable holders on a polishing machine for mechanical finishing and polishing, as desired.

INTRODUCTION AND ACKNOWLEDGMENTS.

DURING a current intensive mineralogical and chemical study of Butte metallization and attending wall rock alteration, several departures from available published procedure used in the preparation of thin sections and polished thin sections have been found useful at the Anaconda Copper Mining Company's Geological Research Laboratory. Consistent encouragement from Mr. Reno H. Sales, chief geologist, Anaconda Copper Mining Company, who instigated and supervises the Laboratory's research program, has provided the stimulus as well as the means for experimenting with certain new devices and materials. With his permission the results are recorded here in the hope that they may prove useful to other workers. Helpful suggestions were also contributed by M. H. Gidel, C. H. Steele and other members of the geological staff, as well as by the writer's co-workers at the Laboratory, W. H. Swayne, research geologist, and R. E. Jones, laboratory technician.

IMPREGNATION OF FRIABLE SPECIMENS.

Clay-rich rocks, or other specimens that will not withstand mechanical treatment of sectioning without reinforcement, are impregnated, using a vacuum, with lucite monomer.[1] The use of lucite has the advantage that no additional special treatment need be given the impregnated specimen throughout the rest of the routine preparation for examination with the microscope. It may be shaped on the diamond saw and finishing lap using water or

[1] First applied to geological techniques by James F. Bell: Notes on the uses of methyl methacrylate "lucite" in a geological laboratory. ECON. GEOL., 34: 804–811, 1939.

kerosene as lubricant, and it may be mounted at 130° C.–140° C. without appreciable warping or softening. The mounted section may be cut on the thin section saw in kerosene lubricant and machine polished using other petroleum lubricants. Lucite is not affected by ordinary index fluids or etch reagents applied under the microscope.

The time of polymerization is shortened by placing the specimen in an expendable glass jar of appropriate size, filling the jar with sand until the specimen is covered to a depth of about one-half inch, and then pouring in uninhibited lucite monomer until it just covers the sand. This jar is then exhausted in a vacuum, covered but not sealed, and heated in a water bath at about 90° C. for 10–12 hours. Mr. Jones has found that the sand, in addition to saving lucite and greatly facilitating diamond sawing, seems to keep frothing at a minimum. Satisfactory bonding has been obtained even in montmorillonite-bearing rocks which swelled beyond recognition during slow, low-temperature polymerization using monomer dewatered by $CaCl_2$ over night. Such careful dewatering is apparently not necessary in the above procedure, and a freshly washed quantity of monomer may be used immediately. Polymerization is completed over night in Anaconda's Laboratory. The glass container may then be chipped off and the specimen sawed, trimmed, mounted and finished without additional special attention.

MOUNTING ROCK SLICE TO OBJECT GLASS.

When possible, all specimens, whether for thin section or polished thin section, are rapidly trimmed to uniform size on a Felker Di-Met diamond saw using water or kerosene lubricant. The best size is a slab (about ¼ inch to ⅜ inch thick) small enough to permit the mounting medium to form a buttress about 1/16 inch wide all around the rock slice when the latter is mounted on whatever object glass is used. The outline of the object glass is simply traced on the rock slab and the saw cuts made inside the traced lines. Though smaller rock chips may be used if necessary or desirable, uniformity of this shaping process facilitates uniform cutting during thinning as well as polishing. Also it is a guarantee for marginal comparison of index of refraction between rock or ore minerals and mounting medium, and it helps keep the edges from tearing loose on the polisher.

Great care should be taken to flatten the surface which is to be placed against the object glass. If the section contains sulphide grains which are to be polished, no abrasive coarser than American Optical 303½ should ever be used. Water or kerosene may be used to suspend the abrasive for this process; kerosene permits smoother cutting.

In a search for a suitable thermoplastic mounting material the writer has experimented with twenty-odd prepared bonding agents over a period of three years. Of the group tested, including those suggested and described by Kennedy,[2] Lakeside No. 70 thermoplastic cement, manufactured by Lakeside Chemical Corp., Chicago, seemed to be the most satisfactory considering

[2] Kennedy, G. C.: The preparation of polished thin sections. ECON. GEOL., 40: 355–359, 1945.

all the qualifications to be met. It is virtually colorless in thin films, and has a refractive index of 1.54 which is of the same order as balsam (glycol phthalate, 1.572; gelva V–7, 1.467[3]). It is insoluble in various petroleum lubricants. It will flow very readily at 140° C. to form a uniform thin film between object glass and rock—an important attainment for mechanical thin section cutting (Gelva V–7 is much more viscous even at 200° C.). It is even more convenient to apply than Canada balsam since it is available in inexpensive stick form. It needs only to be touched to rock and object glass on a hot plate and the bond is made without "cooking" to proper viscosity. It is thus necessary to keep the rock at 140° C. for only a few seconds. Lakeside No. 70 saws and grinds without readily sticking or taking up abrasive. It gives a firm bond between rock and glass to withstand the frictional drag of mechanical polishing.

Cover glasses for ordinary thin sections may be cemented on with balsam in the conventional manner. Since it is slightly more viscous than balsam at 130° C., Lakeside No. 70 holds the section together while the cover glass is applied—normally a rather difficult procedure for a beginner, as suggested by Kennedy.[4] Having similar indices of refraction, the two media are not distinguishable from one another in the covered section.

THIN SECTION CUTTING.

The relatively long and tedious grinding process between mounted rock slice and thinned section is circumvented to a major extent by the use of a specially designed diamond saw, by means of which sections may be cut rapidly and uniformly to low order colors in quartz. The saw in use at Anaconda's Laboratory was adapted from the bearing and shaft assembly of an old Eimer and Amend faceting machine and a discarded machine lathe compound. The only essential features of the bearings are that they are true and free from end play. The compound feed must be fairly heavy and tight and mounted on a turntable (Fig. 1, J) so that its track can be brought into perfect alignment with the saw blade.

On top of the compound is mounted a section-holding device. This consists essentially of a steel block (Fig. 1, B) capable of swing adjustment (Fig. 1, D) to align it laterally, and a lift (Fig. 1, E) to align it vertically, exactly parallel to the saw blade. This block serves as the buttress against which the object glass of the mounted rock slice is placed. To hold the slice in place a universal clamp (Fig. 1, A) is brought against it on the side opposite the object glass and bolted in place. Flanges at the leading edge of the buttress block and the trailing edge of the universal clamp prevent the rock slice (Fig. 1, G) from slipping backward or forward during cutting. The bottom edge of the object glass rests on that slight projection of the base block (Fig. 1, C) which forms one wall of the notch where the saw blade travels. The bottom of the blade, while making the cut, should pass at least ¼ inch below the lower edge of the object glass. The base block is capable of movement on a track oriented perpendicularly to the axis of the compound.

[3] Idem, pp. 357, 359.
[4] Idem, p. 357.

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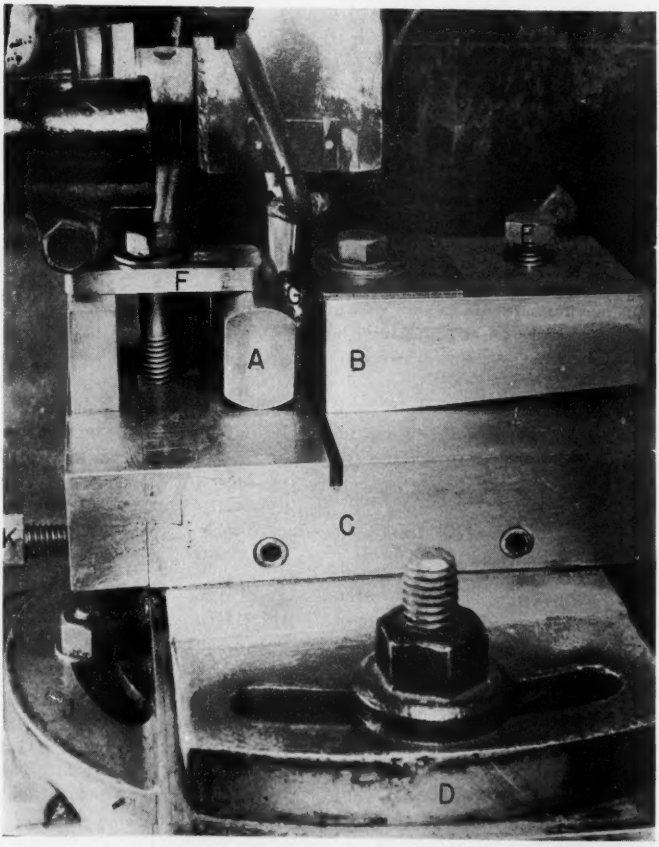

FIG. 1. Diamond saw assembly used for cutting thin sections. The letter designations correspond to the descriptions in the text: (A) universal clamp block, (B) buttress block, (C) base block, (D) swing above feed track, (E) vertical "lift" adjustment, (F) clamp bar for universal clamp, (G) mounted rock slice, (H) lubricant dispenser, (J) turntable below track, (K) end bolts, for adjustment of thickness of section.

This adjustment is made by tightening the two end-bolts (Fig. 1, K) against one another. It controls the thickness of the resulting section.

A six-inch sintered diamond blade, made by Consolidated Diamond Tool Corporation, Yonkers, New York, is used on the present machine. Kerosene is used as the lubricant. It is supplied to the cutting edge by jets on either side of the blade (Fig. 1, H).

About three minutes are required to make the cut on an average full section. If desired, the remaining rock sliced off the section may be remounted and another section cut, separated from the first only by the width of the saw cut. In a few more minutes, a section covering the full object glass may be finished down to 0.03 mm. using a coarse polishing abrasive in water or kerosene on a flat lap or even a glass plate. Sections for polishing are frequently transferred directly from the saw to the mechanical grinding stage without hand retouching other than low angle bevelling of the edges. Mr. Jones has found that necessary corrections of thicknesses may often be made by varying the position of the small weight on the back of the section holder (Fig. 2, A). The deep shattering of susceptible sulphides by coarse abrasives is thus avoided in preparing the thin section for polishing.

A few changes in the design of the thin section cutter are anticipated, to be effected when materials and time become available. In an effort to eliminate vibration, a one-piece casting of the frame is projected, and a slightly heavier guage saw blade with finer diamond dust will be used. A machine-driven feed with automatic cutoff will eliminate the necessity of continuous attention by the operator during cutting. He may then mount and cut simultaneously, thereby decreasing the time assigned to each section. Direct smooth cuts down to 0.03 mm. instead of 0.08 mm. are the objective in view.

POLISHED THIN SECTIONS.

In addition to certain incidental advantages of uncovered sections, such as direct determination of index of refraction of an unknown non-opaque grain, it is frequently of considerable importance, as Kennedy [5] and others have pointed out, to be able to study the inter-relationships between the opaque minerals and the non-opaque gangue in the same section. Most of the foregoing technique was evolved to facilitate routine mechanical polishing of thin sections for this purpose. To accomplish the polishing an adjustable section holder (Fig. 2) was designed to grip firmly any conventional object glass and fit it to a cradle of the Graton-Vanderwilt Polishing Machine used at the Anaconda Company's Laboratory. "Polthins" and ordinary briquettes may be polished at the same time.

The recommended polishing procedure is then used except that, since very little grinding need be done on the first lap, the first polishing abrasive (instead of a coarser size) is used on the steel. Since Lakeside No. 70 is slightly soluble in xylene, kerosene must be used instead to wipe the sections between stages. Also, in order to prevent the frictional heat of polishing from softening the cement of the "polthins," a water cooler pan was designed to occupy the narrow space between the lap and the main casting of the polisher. Water is supplied to the bottom of the lap by small jets in a copper pipe soldered to the bottom of the pan. Water deflected from the lap is drawn off by means of a drain tube similar to the inlet tube, except that the holes are on the under side instead of the top side. A vacuum pump operating off the water supply line, as suggested by Mr. W. H. Swayne, facilitates this

[5] Idem, p. 360.

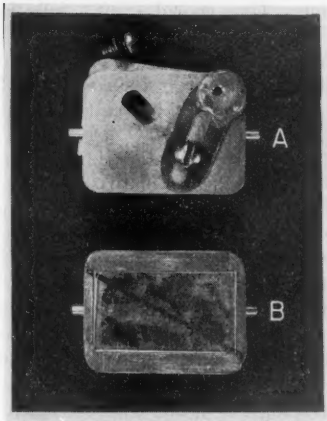

FIG. 2.

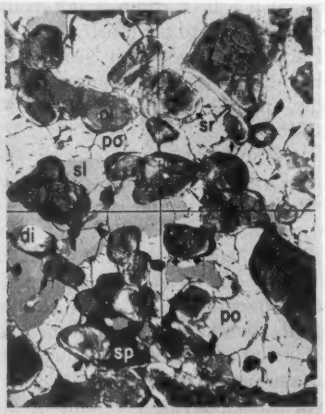

FIG. 3.

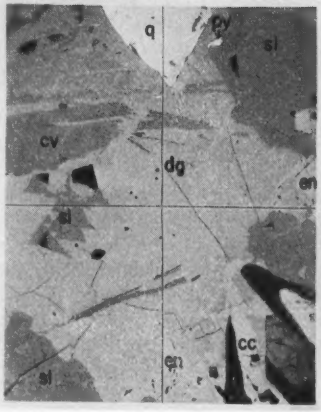

FIG. 4.

FIG. 5.

FIG. 2. (A) Top view of section holder for mechanical polishing of thin sections. The lead compensating weight may be moved over any point in the section to vary the grinding rate if the section needs special compensation. The same bolts adjust the lower slide plates to grip the section firmly by its edges. (B) Bottom view of holder, showing thin section in place.

FIG. 3. Polished thin section in plane reflected illumination and crossed-nicol transmitted illumination: po, pyrrhotite; sl, sphalerite; di, diopside; ol, olivine; sr, serpentine; sp, spinel; × 50.

FIG. 4. Polished thin section in plane reflected illumination and crossed-nicol transmitted illumination: cv, covellite; cc, chalcocite; q, quartz; sl, sphalerite; en, enargite; dg, digenite; py, pyrite; × 50.

FIG. 5. Same field as Fig. 4, in plane transmitted illumination and crossed-nicol reflected illumination; × 50.

operation if a floor drain is not available. Thus cooled, even a fully loaded lap remains cold to the touch.

Hand polishing of thin sections, as described by Kennedy,[6] is no longer used at the Anaconda Company's Laboratory, though Lakeside No. 70 is equally applicable to such a process if machine polishing equipment is not available.

For convenience in use with "polthins" as well as ordinary thin and polished sections, a microscope table with fixed reflected and transmitted light sources has been found convenient. Easily reached toggle switches operate both circuits simultaneously, alternately, or independently. Etch reagents, index fluids, and various microscope accessories are recessed under false tops in the table to obviate lost time gathering equipment and keeping it clean. All adjustments and distances are also thus standardized, minimizing errors involved, for example, in routine systematic recording of desirable "fields" on color film, or in estimating quantitatively the relative amounts of anisotropy of certain opaque minerals.

The accompanying photomicrographs (Figs. 3, 4, and 5) were taken during routine work on miniature film using only the optical equipment of the microscope.

ANACONDA COPPER MINING COMPANY,
BUTTE, MONTANA,
Nov. 10, 1945.

[6] Idem, p. 356.

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DISCUSSION AND COMMUNICATIONS

THE SOURCE OF ORES.

Sir: Charles Henry White's article entitled "The Abyssal *Versus* the Magmatic Theory of Ore Genesis," in the August 1945 issue of ECONOMIC GEOLOGY, pointed out some interesting and useful applications of physical and chemical laws to the problems of geology; but his conclusion: "If an intrusive is the mother of an ore body resting on its shoulder, then a bird's nest on the branch of a tree must be fruit of the tree!" is hardly justified.

In applying chemical and physical laws (laws that have been established by *experiment*) to geologic processes that are outside the realm of direct human observation, one must be sure that: (1) the laws hold true over the range of conditions under which the geologic process operates, and (2) the problem is viewed from a perspective wide enough to include *all* the factors affecting it. Mr. White showed that differentiation of elements would take place in a cooling planet, the denser elements settling toward the center of the earth because of gravity. The order of settling would not be altered greatly by chemical reactions because the heavier metals have lower heats of formation and therefore would form compounds later than the lighter metals. It is inferred that, as the density at the center of the earth is known to be about 11.2, only those elements having densities greater than 11 are present there; namely, lead, thallium, mercury, tungsten, uranium and gold. This fails to take into consideration the increase in density due to the enormous compressive forces at great depth.

It is contended that ores have risen from abyssal depths through breaks in the silicate crust, and that bodies of magma are inadequate to supply the ores. Mr. White says, ". . . (The) important question of how a body of magma so limited in size can be so all-inclusive after the long period of differentiation in the fluid mass of the earth as a whole before a solid crust began to form, has been generally ignored." As a matter of fact, chemical analyses and studies of minor elements have proved that igneous rocks *are* nearly "all inclusive," and although many elements are present in very small per cent, their total amount is large. We know of no great upwellings of ore such as might be expected from a "break . . . through the silicate crust to the ore zone." On the other hand, the facts of the wide dissemination of the heavy metals in the earth's crust and the rarity of concentrations that can be mined as ore, favor the theory of differentiation from a magma.

Many factors might have prevented a complete differentiation during the cooling of the earth, such as: viscosity or rigidity caused by great pressure even at high temperature (We know that the center of the earth transmits earthquake waves that indicate rigidity), trapping of small per cents of heavy

elements in the crystals of the low density solid compounds that formed first, currents in the fluid mass of the earth, extreme volcanism of the young earth, radioactivity resulting in large-scale nuclear reactions and transmutations and local heating that would reverse chemical reactions. If, on the other hand, we assume that the earth did differentiate completely, we know that the heavy elements have been finding their way into the silicate crust for long ages, particularly into places of magmatic activity, as suggested by Mr. White. They could hardly have risen through magma reservoirs without reacting with and becoming a part of the magma. Thus we are led back to theories of differentiation for the immediate source of our ores. Mr. White says, "Cassiterite being non-volatile would move only with the host magma."

Considerable evidence for differentiation of magmas is known in the field; considerable evidence is known, too, for the water content necessary to carry ore minerals out of the magma. The belief that magmas give off large quantities of water is not based, as Mr. White suggests, only "upon the fact that vast quantities of water are ejected from volcanoes." Lindgren [1] says on this subject, "We know that transitions exist from normal igneous rocks to pegmatites and thence to hydrothermal phenomena." As long ago as 1858, Sorby [2] noticed inclusions of liquid and gas in igneous rock minerals and concluded that water was very important in granitic magma: "The proof of the operation of water is quite as strong as that of heat; and in fact I must admit that in the case of coarse-grained, highly quartzose granites there is so very little evidence of igneous fusion, and such overwhelming proof of the action of water, that it is impossible to draw a line between them and those veins where, in all probability, mica, feldspar, and quartz have been deposited from solution in water, without there being any definite, genuine igneous fusion like that in the case of furnace slags or erupted lavas."

Mr. White says, ". . . (The magmatic theory) has been so generally and confidently accepted, that when no igneous intrusive can be found which might reasonably be suspected of being the mother of the ore, one is unscrupulously postulated to be in hiding just out of sight." Most geologists agree that, if ores are differentiated from magmas, they generally are driven out with the fugitive constituents of the magma. Therefore, it is not inconsistent with a magmatic theory that the "mother intrusives" of ore bodies are often not exposed and that the adjacent or containing intrusives of many ore bodies show no evidence of having been the direct source of the ore. Time and place relationships of igneous rocks with many ore bodies do exist. As Mr. White contends, the relationship is, in some places, a structural one, in the sense that the intrusions and ore deposits are together because they entered through the same structures. However, this does not necessarily place the source of the ores below and independent of the *source* of the igneous rock. Neither is the fact that most intrusions have no associated ore bodies inconsistent with a magmatic theory, for we would expect the differentiation and concentration of elements (which occur in small per cents in the magma) to take place only when the combination of many variables happened to favor this. The extent

[1] Lindgren, W.: Mineral Deposits 115.
[2] Sorby, H. C.: Quart. Jour. Geol. Soc. 453, 1858.

of our knowledge about the depths of the earth does not yet permit us to construct well based, detailed theories about the ultimate source of magma and ore, but we should not consider them independently.

In the search for ore, geologists must be wary of empirical rules and impressions, as well as poorly founded hypotheses. It is true, as Mr. White suggests, that a dependence upon the mere place relationship of ore bodies with igneous rocks is highly misleading. Useful observations correlated between many localities and finally tied together by well founded theories are most helpful in prospecting.

GEORGE A. THOMPSON.

OMINATO BAY, JAPAN,
October 1, 1945.

AN APPEAL IN FAVOR OF DESTROYED MUSEUMS.

Sir: The Mineralogical Museum of the University of Liége, Belgium, was destroyed by fire on September 7, 1944, the day the Germans were leaving the city. On February 20, 1945, the Council of the Mineralogical Society of America voted to sponsor the proposal that a continental committee be established to appeal for minerals to restore the Liége Museum and appointed Charles Palache as chairman to organize the committee. It is not known yet what damage has been suffered by other mineralogical collections in the allied countries, but the committee was instructed by the Council to seek to learn the facts and it will consider the needs of other institutions as far as may be possible.[1]

The purpose of this notice is to aid in a continent-wide drive for *mineral specimens* to be presented to the University of Liége as soon as possible. The committee of the M.S.A. is chiefly concerned with gathering specimens and is, therefore, not soliciting funds. Money contributions will, however, be accepted by the Secretary; they will be used to cover expenses or to purchase mineralogical books and equipment. The Belgian-American Educational Foundation of New York (Dr. P. C. Galpin, President) has kindly agreed to pay for the shipment of the gifts from America to Belgium.

Three kinds of specimens are needed: (1) display; (2) teaching; (3) research. Reprints of scientific papers may best be mailed directly by the authors to the Museum in Liége. If other gifts are contemplated (such as books, wooden models, apparatus), special arrangements should be made through the Secretary of the Committee, Dr. Donnay.

Each specimen should be carefully wrapped with its original label signed by donor. A catalogue filing card ($3'' \times 5''$), white, preferably unruled and punched, should be typed, giving: name of mineral, locality, size of specimen in centimeters and a short description of features illustrated, name and address of donor. If you do not happen to have such cards, please use pieces of plain white paper of the same size. The filing cards will be assembled into a catalogue to be shipped to Liége along with the collection.

[1] Since this text was written the needs of two other museums have been brought to the attention of the Council: Caen, France, and Kiev, Ukraine.

Specimens should be sent prepaid to one of the curators: Mr. Charles R. Toothaker, The Commercial Museum, 34th Street below Spruce, Philadelphia 4, Pa., U.S.A., or Dr. V. Ben Meen, Director, Royal Ontario Museum of Mineralogy, Toronto 5, Canada. The corresponding filing cards should be mailed (separately) to the same address. In the improbable event that too many specimens of one species are received, the committee will use its discretion and offer such samples to other devastated museums where they will do the most good or, if the donor desires, will return them to him by express, C.O.D.

The continental committee would welcome the formation of local committees under the sponsorship of local mineralogical or geological societies or departments of colleges and universities. Three such committees are already functioning, under the sponsorships of the Philadelphia Mineralogical Society, of the Walker Mineralogical Club of Toronto, and of the Mineralogical Society of Utah.

In conclusion the undersigned wish to express their confidence that all mineral lovers of America will want to do their utmost to make this project a success.

CHARLES PALACHE, *Chairman,* Harvard University, Cambridge 38, Massachusetts

J. D. H. DONNAY, *Secretary,* Johns Hopkins University, Baltimore 18, Maryland

HUGH ALEXANDER FORD
EDWARD P. HENDERSON
WALTER F. HUNT
V. BEN MEEN
ARTHUR MONTGOMERY
JOSEPH MURDOCK
FREDERICK H. POUGH
AUSTIN F. ROGERS
S. J. SHAND
CHARLES R. TOOTHAKER
R. C. VANCE
C. D. WOODHOUSE

REVIEWS *

Volcanoes Declare War. By T. A. JAGGAR. Pp. 166; pl. 32, figs. 34. Paradise of the Pacific, Ltd., Honolulu, 1945. Price, $3.75.

This interesting volume on "logistics and strategy of Pacific volcano science" summarizes Dr. Jaggar's lifelong rich experience with volcanoes. It is not a volume of abstruse science for scientists, but in Dr. Jaggar's well known scintillating language he writes informally for the interest of everyone. He exhibits "startlingly, events that were startling" in language that commands interest and holds attention.

In 21 chapters Dr. Jaggar tells of the various volcanic centers and chains of the Earth under such dramatic titles as "Army aviators successfully bomb Mauna Loa," "Tarawera disastrously remodels a lake," "Java's gas warfare and Bali's lava flows," "Taal and Mayon are killers," "Alaska disclosed hidden guns in 1912," "The amphibian jeep of the Pavlov Expedition," and "California heat can run engines." Much valuable scientific information, as well as fascinating stories, is given under these interesting titles. The volume concludes with a review of volcano science.

There are many excellent diagrams and photos and entrancing beautiful colored plates.

The book will be invaluable to all geologists and science teachers and a delight to all serious readers.

The Earth and the State, a Study of Political Geography. By DERWENT WHITTLESEY. 1944 edition. Pp. 618; figs. 85. Henry Holt and Company, Inc., New York, 1944.

This new edition follows the general lines of the 1939 edition but with corrections and revisions necessitated by the intervening war. Its 18 chapters deal with the following subjects, which convey the content: Geographic Features of the State, The State and Communication, Political Geography and Localized Resources, The Oceans as International Areas, The Coastland State and World Power, France—Archetype of the Occidental National State, A Conflict of Maritime and Interior Interests—Germany, East Central Europe Exemplified in Its Capitals, The Mediterranean Realm, Geopolitical Structures in Europe, Africa—an Exploitable Continent, Geopolitical Antithesis in the Americas, Latin America, Latin American Boundaries and Capitals, The Antecedent Boundary between the Americas, The Geopolitical Structure of North America, Earth Impress on Political Thought, Earmarks of Political Geography.

The book combines economic and political geography, is highly informative, non-technical, and makes interesting reading.

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, M. M. Leighton, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

BOOKS RECEIVED.

RICHARD J. ORDWAY.

Reconnaissance Survey of the Headstone Mining District, Rio Arriba, New Mex. T. D. BENJOVSKY. Pp. 10; map, scale 1:500. State Bu. of Mines and Min. Resources Circ. No. 11. Socorro, New Mex., 1945. *History, geology, and future possibilities of gold production.*

Pontotoc County Mineral Resources. R. R. PRIDDY AND T. E. MCCUTCHEON. Pp. 139; figs. 15; pls. 1. Miss. Geol. Sur. Bull. 54. University, 1943. *Clay and bauxite.*

Geology and Ground-water Resources of the Camp Shelby Area. G. F. BROWN. Pp. 70; figs. 8; pls. 7; tables 9. Miss. Geol. Sur. Bull. 58. University. 1944. *If pumpage increased to 5,000,000 gallons a day, water-level decline would be less than 5 feet.*

Geology of the Ropes Gold Mine, Marquette County, Michigan. Bull. of Mich. College of Mining and Technology. Vol. 18, No. 2. Pp. 115–128; figs. 2. Houghton, 1945. *Ore body averaging 13 oz. gold and .7 oz. silver occurs as pyritic dissemination in schist.*

Pegmatitos ambligonita, Berilo, Tantaliferos do Ceara, Nordeste do Brasil. W. D. JOHNSTON, JR. Pp. 43; figs. 15; photos 9. Depto. Nac. da Producao Mineral No. 66. Rio de Janeiro, 1945.

Distribuicao Geografica das Jazidas Minerais and Distribuicao Geografica da Industria Mineral, do Brasil. Depto. Nac. da Producao Mineral. Rio de Janeiro, 1945. *Maps showing distribution.*

Mica. Lavra do Bananal, Pecanha—Minas Gerais, No. 67; Na Serra dos Lourencos Pecanha—Minas Gerais, No. 68. W. T. PECORA E A. L. M. BARBOSA. Depto. Nac. da Producao Mineral. Rio de Janeiro, Brasil, 1945. *Occurrences and reserves of mica.*

Natural Light-weight Building-block Materials of New Mex. T. D. BENJOVSKY AND D. M. CLIPPINGER. Pp. 3. State Bu. of Mines and Min. Resources Circ. 10. Socorro, New Mex., 1945. *Building blocks from volcanic rocks.*

The Expanding Mineral Industry of the Adirondacks. H. F. OTTE. Pp. 50; figs. 10; tables 22. Dept. of Commerce. Albany, N. Y., 1943. *Preliminary coverage of recent mineral and mining developments in N. Y.*

Ground-water Conditions along the Ohio Valley at Parkersburg, West Virginia. R. M. JEFFORDS. Pp. 57; figs. 19; tables 11. West Va. Geol. Sur., Morgantown, 1945. *Recharge of well-fields from Ohio River.*

Bibliography of the Geology of Missouri. D. K. GREGER. Pp. 294. Miss. Geol. Sur. and Water Res. Rolla, 1945.

Recent Drilling in Northwestern Missouri. F. C. GREENE. Pp. 153; figs. 14; maps 14. Miss. Geol. Sur. and Water Res. Report of Invest. No. 1. Rolla, 1945.

Biennial Report of the State Geologist. E. L. CLARK. Pp. 94. Missouri Geol. Sur. and Water Res. Rolla, 1945. *Value of mineral production during past ten years, and summarization of principal activities of mineral industries in 1943 and 1944.*

Mining Industry of Idaho for 1944. A. CAMPBELL. Pp. 229. Boise, Idaho, 1945. *Ores and gravels in 1944 yielded gold, silver, copper, lead and zinc—valued at $40,387,100.*

Mineralogia, No. 7. Pp. 82; figs. 45. Bol. 49, Univ. de S. Paulo. S. Paulo, Brasil, 1945. *Zircon and molybdenite.*

Ontario Bureau of Mines, Annual Reports. Vol. 50, Pt. 1A, 1941, Statistical Review of Mineral Industry, pp. 72; vol. 51, pt. 9, 1942, Geology of Trans-Canada Highway between Hearst and Longlac, by E. L. Evans, pp. 10, map; vol. 52, pt. 6, 1943, Geology of East Bull Lake Area, by E. S. Moore and H. S. Armstrong, pp. 19, map; vol. 53, pt. 5, 1944 and vol. 54, pt. 3, 1945, Natural Gas and Petroleum in 1943 (pp. 80) and 1944 (pp. 92) by R. B. Harkness. Prov. of Ontario. Dept. of Mines. Toronto, 1945.

SOCIETY OF ECONOMIC GEOLOGISTS

ANNUAL BUSINESS MEETING AND TECHNICAL SESSIONS.

December 27–29, 1945, Pittsburgh, Pennsylvania.

The sessions here described were held jointly with the Geological Society of America, the Mineralogical Society of America, the Paleontological Society, and the Society of Vertebrate Paleontology. The annual meeting of the Society of Economic Geologists and the cooperating societies included some three days of technical sessions, during which 59 scientific papers were presented, essentially as listed and abstracted in the program published in the December issue of this *Journal*.

On the night of December 27, at the *All-Geological Smoker*, President Oscar E. Meinzer gave the *Presidential Adress*, "Hydrology in Relation to Economic Geology." This was followed by papers by the presidents of the cooperating societies. The Society joined the Geological Society of America and its affiliates at a formal dinner on the night of December 28.

The Council of the Society met during the luncheon period on the 27th and from 2 until 10 p.m. on December 29. Some of the results of its deliberations were summarized at the Annual Business Meeting described below.

The Annual Business Meeting of the Society was held on December 28 with President Meinzer in the chair. After his introduction, Dr. F. A. Vening-Meinesz of the University of Utrecht, the Netherlands, present as a guest of honor, addressed the Society with a few cordial words of friendship "across political boundaries." A vote of thanks was extended to the host group, the Pittsburgh Geological Society, through its President, Mr. George C. Grow, Jr., the other guest of honor.

The members deceased during 1944 and 1945 were named and (see the Secretary's report below) their memory was honored by a minute of silence.

It was announced that the following new members whose election was carried out during the spring of 1945 and confirmed by the Council, had been duly made members of the Society:

Andrews, T. G.	Hopper, C. H.	Meyerhoff, H. A.
Barksdale, H. C.	Howse, C. K.	Miller, H. W.
Brown, G. F.	Koenig, R. P.	Oder, C. R. L.
Hagner, A. F.	Landwehr, W. R.	Piper, A. M.
Hershey, H. G.	Lund, R. J.	Weissenborn, A. E.

The following officers were declared elected, the ballots having been examined by tellers, whose certification of election was accepted by the Council:

President-Elect (taking office in 1947): George H. Ashley.
First Vice-President-Elect (taking office in 1947): George M. Fowler.
Regional Vice-Presidents (taking office in 1946):

David Williams, Europe	Ezequiel Ordonez, North America
P. K. Ghosh, Asia	Jorge A. Broggi, South America
Rene A. Pelletier, Africa	R. Lockhart Jack, Australia

New Councilors (serving from 1946 through 1948):

Frank R. Clark Joseph L. Gillson V. T. Stringfield

The reports of the President, Secretary, and Treasurer were submitted and are printed below in condensed form. It will be noted that they in part anticipated, in part reviewed actions reported to the Society Membership at the Annual Business Meeting.

Several major steps taken by the Society or the Council since the last Annual Business Meeting of the Society were described by various officers and committee chairmen. A brief summary of these is given below.

The Special Committee on the Annotated Bibliography of Economic Geology (Messrs. H. R. Aldrich, Chairman, Sidney Paige, and J. T. Singewald, Jr.) after conferring with Mr. E. R. Lilley, Chairman of the regular Editing Committee of the Bibliography, recommended that the Geological Society of America, through its regularly employed bibliographers, undertake coverage and abstraction of articles. The Board of Editors is to modify the abstracts as desired and add summary sections on individual units. This plan in outline has been approved by the Council. Mr. W. H. Newhouse, Editor of the volume on "Ore Deposits as Related to Structural Features," and the other co-authors have generously allotted all profits from royalties, hitherto devoted to cancelling the publication costs, to the future support of the Annotated Bibliography.

The Publications Committee (Messrs. E. S. Moore, Chairman, K. C. Heald, and G. F. Loughlin) had been requested by the President to consider and report upon the advisability of appointing a Committee on Basic Research. After due study the Publications Committee recommended that such a committee be created as a separate entity, and outlined its possible structure. The Council subsequently authorized appointment of the Committee by the President, in general accordance with these recommendations.

A special committee on Revision of the By-Laws (Messrs. T. G. Moore, Chairman, W. O. Hotchkiss, and D. H. McLaughlin) has been named to suitably revise the by-laws and, among other things, to simplify the procedure of nominating and electing new members to the Society. This committee has begun its work with energy and rendered a progress report at the Council Meeting of December 29.

A report of the past year's work of the National Research Council was given by the Secretary, who has this year been the Society's representative on the Executive Committee of the Geology-Geography Section of the Council. This report was published in the January-February issue of *Economic Geology*.

A progress report was also given by Mr. H. E. McKinstry, the Society's representative at a meeting of delegates from geological and affiliated societies who held a meeting designed to consider the organization of an all-geological association, congress, or committee. He briefly summarized the results of the meeting, stating that two committees had been designated to study (1) the needs of the profession and (2) the desirable procedure and framework for cooperation. Mr. McKinstry has been reappointed the Society's representative during the next year.

It was announced that the Secretary had been instructed to set in train proceedings for affiliation between the Society and the American Association for the Advancement of Science; final action was deferred for further consideration by the Council, which, at its meeting on the 29th, confirmed these instructions.

Below are given the texts of reports from the officers for 1945.

REPORT OF THE PRESIDENT.

During the past year the principal efforts of the officers and members of our Society have been devoted to the winning of the war, and Society activities have purposely been kept on a moderate scale. However, constructive work has been done on a number of rather important projects. The Society is in a stable and healthy condition, with an encouraging outlook. It represents an important and growing profession and branch of applied science. I believe it is wholesome for us, in the midst of necessary discussions of sundry problems, to take time to maintain our perspective and to recognize the substantial achievements of our Society in the past and the good program of activities which will be resumed effectively in the post-war years—our annual technical meetings, alternately with the American Institute of Mining and Metallurgical Engineers (which gives us valuable professional contacts) and the Geological Society of America (which maintains contact with our own science of geology); the support of our official journal, *Economic Geology,* and of the *Annotated Bibliography of Economic Geology;* and our world-wide outlook and contacts. On the other hand, we must not be content with our past achievements and present status. There are several questions before the Council this year which, if handled wisely and constructively, will add materially to our effectiveness. Unfortunately, time is not available to discuss these questions in this brief report, unless very briefly, but I will mention them for the information of the Society.

1. The most important question this year relates to the future of the *Annotated Bibliography of Economic Geology.* I hope that, through the cooperation of the Geological Society of America, the plan will be consummated whereby systematic preparation of the bibliography will be provided, but under the supervision of a strong staff of specialists, who will rewrite the abstracts of the most important publications and will prepare summaries of each year's progress in the several subdivisions of economic geology as shown by the publications listed in the bibliography. This plan should put the bibliography on a more workable, businesslike basis, and at the same time preserve and, I hope, strengthen the high ideal of its revered founder, Doctor Lindgren.

2. There is at present no proposal to change the membership requirements, but there is an active program on the part of the Membership Committee, or Committee on Admissions, to enlarge our membership from the numerous economic geologists who are not now members but who have the requirements specified by the By-Laws. It is my understanding that this program has the general approval of the Council and membership. If it is continued in future years, it should result in decided strengthening of the Society. The present procedure in regard to candidates for membership is very cumbersome and expensive. The question of simplification of this procedure will come before the Council.

3. A research program in economic geology has for some time been advocated by some of our members. Now that the war is over the time is opportune for consideration of this project. Accordingly, the Committee on Publications is to submit a report to the Council on a plan to establish a research program and a permanent Committee on Research.

4. A special committee will report to the Council a proposed systematic revision of our By-Laws to improve the arrangement and wording, remove ambiguities and needless statements, and add sections authorizing committees and procedures that have long become established. The proposed revision is to include only such new legislation as will likely receive unanimous consent. Changes in policy are not contemplated in this revision.

5. The proposal for an American Geological Institute or other federation of the geological societies of the United States, and perhaps Canada, will come up for further consideration, and a report will be received from our committee of one on this subject.

6. Affiliation with the American Association for the Advancement of Science will receive consideration by the Council. Most of the leading American scientific and engineering societies and a large number of smaller societies are affiliated with the Association. Affiliation affords certain advantages and involves no responsibilities that would be difficult to fulfill.

7. Another important subject that will come before the Council is that of providing for regional meetings of the Society in different parts of the United States and especially in the West, where so much of the mineral industry is located. When the Section of Hydrology of the American Geophysical Union was organized fifteen years ago, it was recognized that it could not become a truly National organization if all its meetings were held in the East. The plan of holding regional meetings has proved wonderfully successful. I believe that, likewise, regional meetings of the Society of Economic Geologists would put added life into the Society, enlarge its membership, increase its usefulness, and enhance the prestige of the profession of the economic geologists. Affiliation with Section E of the Association would help to make such regional meetings feasible.

8. This is the time also for us to restudy our international policy and program in relation to the International Geological Congress and the prospective scientific organization in the United Nations. A survey should be made of the actual post-war membership outside of the United States to ascertain their views and wishes. Possibly regional organizations and meetings could be promoted on the other continents under the regional vice-presidents. Perhaps these could be affiliated with larger and more comprehensive National organizations comparable to the A.A.A.S. The society should either develop a truly international structure or else abandon the claim that it is more than a National society with world-wide affiliates. It appears that a committee is needed to study this question.

9. Consideration must also be given to questions of finance and budget and related matters, and to certain other questions.

O. E. MEINZER,
President.

December 27, 1945.

REPORT OF THE SECRETARY.

The preceding meeting of the Council was held on February 20, 1945, under the Presidency of Mr. John M. Boutwell. For that time an Annual Business Meeting had also been scheduled, as well as the usual technical sessions of the Society in cooperation with the American Institute of Mining and Metallurgical Engineers. The general meetings were cancelled at the request of the Office of Defense Transportation. The Pittsburgh meetings, held jointly with the Geological Society of America and its affiliates, thus presented the first opportunity in two years to resume our annual sessions and the first joint meeting with the Geological Society since 1941.

Since February, 1945, there were elected 15 new members and another 32 new nominees for membership have been recommended to the Council. Thus some 45 to 50 new members will have been added, an increase in one year of about 10 per cent, to our membership of 485. This growth, though healthy, is regrettably almost wholly from the U. S. A.

Meantime the Society has lost by death four well known and beloved members, Alfred F. Duggleby, Willard L. Cumings, Henry B. Kummel, and R. N. Frantisek Ulrich. Memorials to these men have appeared in ECONOMIC GEOLOGY.

The official tellers have certified the election of the officers whose names were submitted to the membership in August, 1945. Mr. J. T. Singewald has been renominated by the Council and reappointed to the Treasurership. The present Secretary, who tendered his resignation a year ago, is glad to be able to announce that Mr. Olaf N. Rove has accepted nomination as the new Secretary, as of February 15, 1946.

In 1945 the Secretary's Office has been engaged mainly in three kinds of work, each consuming about a third of the time and efforts of the office. The first of these has been the handling of membership nominations. The procedure is most cumbersome, usually requiring at least nine months, with much transcribing of nomination forms, letters of sponsorship, and the like, for use by the Membership Committee and Council. Despite the industrious labors of the Membership Committee, especially its efficient Chairman, Mr. T. M. Broderick, a great deal of the labor of this office has gone into such objectives.

A second field of effort has been personnel problems—the finding and placing of needed geologists in government or private industry; aid in revising upward the respect of public officials for the role of geologists in peace and war; and efforts with fair success at persuading government that geologists are and need to be highly trained Some of this work was individual, but most of it was in cooperation with our sister societies, such as the Geological Society of America, the American Institute of Mining and Metallurgical Engineers, the American Association of Petroleum Geologists, and the National Research Council. Most of these groups have moderate-sized "full-time" staffs and so are able to bear a most important share of the heavy duties incidental to such work, luckily for us; but our society, too, did its significant part. Basic to many such problems of personnel and public relations is that of finding a common organization around which geologists as a whole may rally.

A third major part of our work has been devoted to sharing with the Program Committee the heavy duties of arranging the scientific and technical meetings. Most of the effort that went into planning the sessions for February, 1945, came to naught so that the hard work of Mr. H. E. McKinstry, then Program Committee Chairman, did not receive the recognition that it merited. The sessions for the Pittsburgh meeting, decided upon on rather short notice, were effectively planned by the 1945–46 committee, especially its chairman, Mr. J. W. Peoples, who was largely responsible for organizing the symposium on military geology. His fellow committee-men likewise contributed. Mr. V. T. Stringfield organized the symposium on ground-water recharge. To Messrs. J. M. Schopf and G. H. Cady belongs much credit for the symposium on coal composition and to Mr. McKinstry for several of the papers on ore deposits, salvaged from the cancelled February 1945 program. Joint meetings of the sort held at Pittsburgh require great and constant adjustments with the collaborating societies—the G.S.A. or the A.I.M.E., as the case may be.

During the past ten months the types of work mentioned above and other special activities necessitated sending out from the Secretary's offices some 2100 letters and cards, in addition to approximately 2000 routine notices, ballots, and the like.

Of special importance for the proper functioning of the Society are certain items, mentioned here partly because they were handled in some degree by the Secretary's Office, but largely to call them to the attention of the membership.

Our by-laws are too detailed in many respects, while lacking certain essentials. They specify how many votes "may" (but not "shall") debar a nominee, but they fail to indicate what is a quorum! A special committee is engaged in a much-needed revision and the Council and Membership should shortly receive its recommendations.

The Annotated Bibliography of Economic Geology suffered greatly through the war. As a result of the recommendation of a special committee, the Council has tentatively discussed with the Geological Society of America the proposal that the regular bibliographers engaged by the latter be made responsible for coverage and bare abstracting, whereas the Editorial Board and Section Chiefs revise or annotate the completed abstracts, as desired, and prepare significant periodical summaries.

The importance of organizing basic research in the fields generally grouped under economic geology has been recognized by requesting the Committee on Publications to design a Committee on Basic Research, if desirable.

The Secretary welcomes this, his first and last opportunity to make a few concluding comments, based upon intimate personal experience with the affairs of the Society during the last four years. During this period there has been some ponderable growth in membership but a much greater increase in the responsibilities necessarily assumed by the Society. I believe that the continued healthy expansion in influence and especially in usefulness requires that we consciously plan and energetically carry through several major policies.

We should seek to enlist as members competent workers the world over. We especially need: (1) more workers in ground-water, petroleum and engineering geology; (2) more young, active members, nearer the beginning of their careers; (3) more members from other regions than North America—especially from Scandinavia, Switzerland, central Europe, the Mediterranean Region, Russia, and China—to maintain our international outlook. With a regular membership already about two-fifths outside the U. S. A., we have, I believe, a uniquely international rôle to fill.

We need more cooperation with our capable editors, Messrs. Alan M. Bateman and M. M. Leighton, especially on the part of members from outside North America, so that searching, thoughtful articles are offered in larger number to our journal.

We badly need more operating funds, in my opinion. Except for two part-time secretarial assistants, all the work of the Society is really offered gratuitously. Even long distance travel to necessary council or committee meetings, held solely for the purposes of the Society, is financed by the participants. The penuriousness necessitated by these conditions is pitiable, the more so as the Treasurer has shown elsewhere that members receive $8 worth of service per capita for dues of $5, and that it is cheaper to become a member and receive the journal plus the benefits than to enroll as a subscriber.

The society needs a positive program as to problems of personnel and public relations. How shall we aid in securing employment for the competent geologists now available? How may we assure the science that essential work by government surveys will be adequately supported? How can political and military administrators be taught to conserve geologic personnel by retaining it in positions designed to get greatest use out of ability and training?

Finally, the society must take the first steps in organizing and suitably supporting (not only morally but financially as well, if need be) the kinds of research that, upon careful thought, seem most promising for the growth of the basic science and its applications. As in medicine, chemistry, and astronomy, progress

calls not for the haphazard, purely individualist approach typical of the past, but for planning, systemmatically and collectively.

In closing I want to extend my thanks to the associates who have worked so loyally for the welfare of the Society. President Meinzer has generously contributed his time and the most careful consideration to his office, far beyond what we have a right to expect from so busy a man. Treasurer Singewald has for years carried out his difficult duties, while still following a very full professional career as teacher and practising geologist. Finally, I especially welcome this opportunity to speak of the thoughtful, conscientious, and unselfish efforts of my Secretarial Assistant, Miss J. May Lynch, whom the membership has come to know in conferences and through letters as a cordial and most helpful friend.

CHAS. H. BEHRE, JR.,
Secretary.

December 27, 1945.

REPORT OF THE TREASURER

The detailed report for the fiscal year has been submitted to the Council and will be published later in the Proceedings of the Society. It will suffice to present here a summary of the report.

Receipts from members were $2301.87. Disbursements on behalf of members were $2179.85 for Society operations and $1605.95 for members subscriptions to Economic Geology, a total of $3785.80. Consequently, for their $5.00 annual dues, the members received $8.22 in services.

Bibliography expenditures reached the low ebb of $303.26 and receipts were $287.22, leaving a deficit of $16.04 charged to the Annotated Bibliography Fund. The balance in this fund is $261.10.

The Penrose Medal Fund received $138.69 from investments, making the balance $3534.86.

The Endowment Fund was increased to $27,348.02 by the addition of $300.00 from life membership payments.

The investment counsel was replaced by a finance committee. The finance committee sold $25,566.44 in securities at a profit of $625.46, and purchased $32,-094.64 in securities. The revised portfolio had a cost value of $50,435.73 and a market value of $53,908.49 on November 30, 1945. The sale of securities realized accrued interest of $310.00 on U. S. Savings Bonds.

Net income from securities was $1845.00 which was $361.07 in excess of the deficit in Society operations. The latter amount was credited to the Surplus Fund. The balance in the Surplus Fund is $23,036.27.

The total assets of the Society are $54,180.25 on the book value of the securities.

Unpaid dues total $1115.00, but $1035.00 is due from members in foreign countries on moratorium and only $80.00 from members carried as delinquents.

J. T. SINGEWALD, JR.,
Treasurer

December 27, 1945.

ROY JAY HOLDEN

1870–1945

Roy Jay Holden, a Wisconsin youth and student, was born at Sheboygan Falls on October 21, 1870. His undergraduate and graduate training was at the University of Wisconsin, from which he received the B.S. degree in 1900 and the Ph.D.

degree in 1915. He furthered his education by teaching for ten years in the schools of his native state. He was appointed in 1905 to the department of geology at Virginia Polytechnic Institute at Blacksburg, Virginia.

Doctor Holden soon became *the* department of geology at "Virginia Tech." His personal manner, vitality, interest in students, and unquenchable enthusiasm for geology in the field soon made him one of the best known and most respected members of the faculty. He trained and inspired several students to become professional geologists. But he left an indelible impress upon countless other students who absorbed geology in his classrooms as part of their training in engineering.

His influence throughout southwestern Virginia was very great. To many of the graduates of Virginia Polytechnic Institute and to many others, Holden was V. P. I. He seized every opportunity to do field work in that part of the State and to visit other areas as time would permit. Some of his students often accompanied him on these field excursions, for to him geology was not a bookish science but a science and an art to be studied and applied in the field.

Although Holden was primarily a teacher and a laboratory researcher, he found time to act as consultant to many mining firms in the State. His principal interest was in iron and manganese, but covered all mining and quarrying operations. He had throughout the long years gathered a large body of facts about the coal, iron and manganese deposits of Virginia. Always searching for more facts to test his hypotheses of ore genesis, he unfortunately did not publish extensively. He had long had in progress a report on the iron deposits of Virginia, on which he had early published a summary (1907) and shorter papers. His latest contribution was the identification and description of the "Punch Jones" diamond, found along New River.

Holden was at times a member of the technical staff of the Virginia Geological Survey, and was an active member of the Virginia Academy of Science. His pithy comments and somewhat humorous but searching questions always enlivened and stimulated the annual meetings of the Section of Geology. He was a member of the Society of Economic Geologists, American Association of Petroleum Geologists, American Institute of Mining and Metallurgical Engineers, the American Association for the Advancement of Science, and a fellow of the Geological Society of America.

Doctor Holden was taken ill dring the summer of 1945. Although incapacitated for active class-room duties, he continued to hold his classes at his home on the Institute grounds until his sudden death on December 16. His passing leaves a void in Blacksburg and throughout southwestern Virginia.

ARTHUR BEVAN

January 23, 1946.

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SCIENTIFIC NOTES AND NEWS

PHILIP J. SHENON has returned to private practice as a mining geologist after two years as regional geologist for the U. S. Geological Survey at Spokane, Washington, and one year with the Army in the Pacific where he headed an engineering intelligence unit.

W. D. JOHNSTON, JR., has returned to the United States from Brazil, where he spent four years as geologist with the Foreign Economic Administration, to serve as Chief of the Section of Foreign Geology of the U. S. Geological Survey.

QUENTIN SINGEWALD has completed his studies of the tin resources of Bolivia for the F. E. A. and has rejoined the U. S. Geological Survey. He expects to leave for military geology work in Japan in April.

JOHN PAYNE, JR., has been released from active duty in the Navy and has returned as geologist for The American Metal Company, Limited.

JULIAN W. FEISS has received his discharge from the United States Army and has been appointed Editor of *Mining Congress Journal* in Washington, successor to the late Mr. Stanley Trengrove who died in December.

JAMES H. COURTRIGHT, assistant chief geologist for the Consolidated Copper Mines Corporation at Kimberly, Nevada, is working at present with the American Smelting and Refining Company as mining geologist in the exploration department in Salt Lake City.

BEN H. PARKER, vice president of Frontier Refining Co., has been made president of the Colorado School of Mines, succeeding Dr. M. F. Coolbaugh, resigned. Dr. Parker is an alumnus of the School.

H. B. BURWELL has been appointed State Geologist of Tennessee and Director of the Division of Geology at Nashville.

L. A. CROZIER, assistant manager of Wattle Gully Gold Mines, N. L., Chewton, Victoria, has accepted the position of mine superintendent of Patiño Mines and Enterprises Consolidated, Inc., La Paz, Bolivia.

ALFRED E. WALKER, chief geologist of the M. A. Hanna Co. of Cleveland, Ohio, has gone to South America to study ore deposits in Brazil.

A. E. WEISSENBORN, who has been regional geologist for the U. S. Geological Survey at Rolla, Mo., has been transferred to the northwest regional office of the Survey at Spokane, Wash. Mr. Weissenborn will be in charge of his new station.

The California Institute of Technology announces the addition of two men to the staff of the Division of the Geological Sciences: DR. J. WYATT DURHAM as Associate Professor of Invertebrate Paleontology, and DR. RICHARD H. JAHNS as Assistant Professor of Geology. Dr. Durham received his Bachelor's degree from the University of Washington, his Master's and Doctor's degrees from the University of California. He was formerly a geologist for the Standard Oil Company of California in the Netherlands East Indies and is currently working for the

Tropical Oil Company in Venezuela. He will join the staff of the Institute in August, 1946. Dr. Jahns received his Bachelor's and Doctor's degrees from the California Institute of Technology, his Master's degree from Northwestern University. For the past several years he has been engaged in studies of strategic minerals, chiefly in New Mexico and in North Carolina. He comes to the Institute in March.

CHARLES CAMSELL, for a long period Deputy Director of Mines and Resources for Canada, and widely known throughout the mining and geological world, has retired from active duty.

MAHLON MILLER, formerly chief of the Metals Division, F. E. A., has left for Siam to carry on mineral investigations in that country for private interests.

WILLIAM C. SCHMIDT, formerly in Latin America for the Foreign Economic Administration, has left the States to make mine investigations in southern Europe and the Near East for private interests.

KENNETH DEP. WÈTSON, associate mining engineer in the British Columbia Department of Mines, has been appointed associate professor in the Department of Geology and Geography at the University of British Columbia.

A. G. UNKLESBAY, who has been with the U. S. Geological Survey in Washington, is now with the Iowa Geological Survey in Iowa City.

G. M. FURNIVAL has resigned as field superintendent with the California Standard Company in Alberta to accept the position of Director of Mines in the Department of Mines and Natural Resources, Province of Manitoba.

RICHARD P. GOLDTHWAITE, formerly of Brown University and during the war in charge of special equipment investigations for the Army Air Corps at Wright Field, has been appointed Associate Professor of Geology at Ohio State University.

The Office of Metals Controller of Canada was dissolved on December 31, and what functions were left were incorporated into the new Department of Reconstruction and Supply. N. B. Davis, formerly Deputy Metals Controller, is now transferred to the position of Deputy Coordinator, Resources Development and Controller of Radioactive Substances; G. C. Bateman continues in Washington as special deputy for the Minister of Reconstruction and Supply; G. C. Monture has returned to Ottawa to take up the reorganization of the Economics Division, Bureau of Mines, of the Department of Mines and Resources.

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